FIFTH BILLINGS SYMPOSIUM

ON

DISTURBED LAND REHABILITATION

Volume I: Hardrock Waste, Analytical and Revegetation

Billings, Montana
March 25-30, 1990

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Volume I

Billings Plaza Holiday Inn, Billings, Montana
March 25-30, 1990

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This publication contains the proceedings of the Symposium on Disturbed Land Rehabilitation. Speakers were asked to submit camera-ready copy for this publication. Because of the schedule for printing, the chairmen were unable to edit the texts and apologize for any errors in the copy or poor reproduction of figures or tables.

Several papers were not received in time to be included in this publication; thus, the lack of conformity between the Agenda of the Symposium and this published proceedings was unavoidable.

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Frank F. Munshower
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TABLE OF CONTENTS

Page

General Session Opening Speakers

1. Cabin Creek Coal Mine Studies and the International Joint Commission — 1
   J. Posewitz
2. Westwide Investigations of Irrigation-Induced Water Quality Problems — 3
   R.A. Engberg
3. Data Adequacy: Challenge of the 1990's - Abstract — 13
   A.A. Sokoloski
4. Soil, Spoil and Waste Materials Analyses and Data Interpretation - Abstract — 14
   P. Sullivan and J. Morotti

Session I A. Tailings Rehabilitation

1. Ecosystems Restoration on Copper Tailings in the Southwest — 15
   S.A. Bengson
2. Column Leach Study I: Heavy Metal Dissolution Characteristics from Selected Copper Mine Tailings — 27
   R.D. Doepker
3. Stabilization of Acidic Mine Tailings in a Pristine Alpine Environment — 41
   D.E. Jewell

Session I B. Cyanide

1. The Use of Attenuation Capacity Studies to Evaluate the Suitability of Soils for the Disposal of Stormwaters from Heap Leach Facilities — 51
   K.J. Lang
2. Land Application of Cyanide-Containing Mining Process Solutions — 60
   W.M. Schafer and T. Hudson
3. Design and Operation of Land Application Discharge Systems for Mineral Processing Effluent — 77
   M. Pearson, T. Grotbo, D. Ortman, E. Griffith
4. Cyanide Neutralization and Reclamation of Heap Leach Projects — 83
   D.W. Struhsacker and A.Smith

TABLE OF CONTENTS (Continued)

Page

Session I C. Other Hardrock Rehabilitation

1. Effects of Minesoil Amendments on Revegetation of Bentonite Mined Lands — 94
   D.J. Dollhopf, S.C. Smith, R.B. Rennick
2. Bonding and Long-Term Liability for Hardrock Mining in Wisconsin — 118
   T.C. Hunt

Session I D. Analytical

1. Assessment of Data Quality — 125
   D.R. Neuman
2. Comparing Four Methods of Selenium Analysis Involving Plant Digestions — 134
   R.N. Pasch, A. Telck, C. Peterson

Session II A. Revegetation

1. Effect of Landscape Position on Spring Wheat Yields and Water Use — 144
   G.A. Halvorson
2. Use of Glyphosate and Interseeding to Improve Seasonality of Reclaimed Grasslands — 154
   K.J. Hirsch and D.J. Nilson
3. Ponderosa Pine Reclamation at the Rosebud Mine — 163
   P.R. Martin
4. Boron Toxicity of Coal Mining Areas in Southwestern Wyoming — 175
   R.L. Hanson, P.W. Smith, J.A. Smith

Session II B. Revegetation (Cont.)

1. Seed Source Differences in Germination Under Snowpack in Northern Utah — 184
   S.E. Meyer

TABLE OF CONTENTS (Continued)

Page

Session II B. Revegetation (Cont.)

2. Seeding Equipment Effects on Establishment of Big Sagebrush on Mine Disturbances — 192
   S.B. Monsen and S.E. Meyer
3. Rooting-Depth of *Atriplex canescens* (fourwing saltbush) in Mine Spoils at the Navajo Mine, Northwestern New Mexico — 200
   H.C. Stutz and B.A. Buchanan
4. Revegetation Observations at Surface Coal Mines in the Axial Basin, Yampa River Basin, and North Park, Colorado — 219
   D.T. Mathews and M.S. Savage

Session II C. Revegetation (Cont.)

1. Plant Species Establishment for Reclamation Purposes on Four Soils at the La Plata Mine in Northwestern New Mexico — 235
   F. Samson, M.K. Wood, B.A. Buchanan
2. Vegetation Associated with the Major Soils and Reclamation Areas on the Navajo Mine, New Mexico — 248
   B.A. Buchanan, M.K. Wood, W. Ruzzo
3. Warm Season Grass Establishment on Surface Coal Mine Reclamation in the Southwest — 258
   D.C. Porterfield

Session II D. Revegetation (Cont.)

1. Native Grassland Bond Release Criteria Using Technical Information and Reference Area Data — 279
   K.J. Hirsch and D.J. Nilson
2. Eco-restoration Model for Surface Mined Lands - Abstract — 290
   P. Soni, H.B. Vasistha, O. Kumar

Session III A, B, C and D. Selenium

These sections will be published by the United States Geological Survey.

TABLE OF CONTENTS (Continued)

Page

Session IV A. Geostatistical, GIS and Data Base Management

1. A Geostatistical and Sampling Analysis of Regraded Spoil Materials — 291
   J.C. Myers and T.H. Brown
2. Using X-Ray Fluorescence Spectrometry and Geostatistics for Mapping Soil-Metal Contamination — 307
   J.P. Walsh, T. Harding, S. Aulenbach
3. Applications of GIS in Mineral Extraction and Hazardous Waste Planning - Abstract — 319
   D. Richardson
4. Development of a Data Base System to Aid the WDEQ in the Evaluation of Surface Mining Permit and Renewal Applications — 320
   W.B. Sanderson

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

CABIN CREEK COAL MINE STUDIES AND THE INTERNATIONAL JOINT COMMISSION

Jim Posewitz[1]

ABSTRACT

In February of 1984, the British Columbia Government granted Sage Creek Coal Limited approval-in-principle for a 2.4 million U.S. tons per year thermal coal mine. The mine was to be located six miles upstream from the International Boundary on Howell and Cabin creeks, tributaries to the North Fork of the Flathead River.

The United States and Montana Governments were concerned about the possible effects of this proposed mine on the Flathead River system, Glacier National Park, and Flathead Lake. In response to these concerns, the United States and Canadian Governments requested that the International Joint Commission (IJC) examine the possible impacts of the proposed mine. This reference from the two governments was made to the IJC pursuant to Article IX of the Boundary Waters Treaty of 1909. The reference also asked that the IJC make recommendations that would ensure that the provisions of Article IV of the treaty were respected. This article states that boundary waters, "... shall not be polluted on either side to the injury of health or property on the other".

To respond to the reference, the IJC appointed the Flathead River International Study Board to undertake the technical assessment to form the basis for their deliberations. The Study Board, in turn, appointed a number of technical committees to conduct the essential detailed analysis. These analyses revealed problems with toxic substances, increased sedimentation, temperature change, flow modification, degraded habitat, dissolved oxygen reductions, increased dissolved solids and others.

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Based on the analysis of the technical committees and the findings of the Study Board, the IJC concluded that, "... damage will inevitably occur to this habitat which would be located in the midst of a major mining development, and consequently to the fishery dependent on that habitat". The IJC further concluded that, "... such losses would ... cause a reduction in ... the sport fishing ... and create a negative impact on the ... economic infrastructure ...". Of particular significance, the IJC found that, "... the pollution expected to cause these consequences to the fishery would thus clearly constitute a breach of Article IV" of the treaty.

The IJC concluded its reports as follows:

"The Commission recommends that, in order that Governments can ensure that the provisions of Article IV of the Boundary Waters Treaty are honored in the matter of the proposed coal mine at Cabin Creek in British Columbia:

1) the mine proposal as presently defined and understood not be approved;

2) the mine proposal not receive regulatory approval in the future unless and until it can be demonstrated that:

    a) the potential transboundary impacts identified in the report of the Flathead River International Study Board have been determined with reasonable certainty and would constitute a level of risk acceptable to both Governments; and

    b) the potential impacts on the sport fish populations and habitat in the Flathead River system would not occur or could be fully mitigated in an effective and assured manner; and

3) the Governments consider, with the appropriate jurisdictions, opportunities for defining and implementing compatible, equitable, and sustainable development activities and management strategies in the upper Flathead River basin.

Since conclusion of the International Reference, the State of Montana and the Province of British Columbia have been discussing the creation of a special international resource management area on the Flathead River. These discussions are continuing.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

WESTWIDE INVESTIGATIONS OF IRRIGATION-INDUCED WATER QUALITY PROBLEMS

R. A. Engberg[1]

ABSTRACT

The potential for problems of trace constituents in irrigation drainwater in places other than Kesterson Reservoir, California, prompted the Department of Interior to begin a program to see whether similar problems existed in Western States at other Department-constructed or managed irrigation projects, national wildlife refuges, or other wetland areas where the Department has responsibilities under the Migratory Bird Treaty Act or the Endangered Species Act. The interbureau program initiated in 1985 has evolved to a five-phase process of site identification, reconnaissance investigation, detailed study, planning, and remediation. About 600 sites have been evaluated and 20 reconnaissance studies are complete or underway. Four more reconnaissance study sites have been selected for 1990 starts. Four detailed studies at Salton Sea, California; Stillwater, Nevada; Middle Green River, Utah; and Kendrick Project, Wyoming; are in their last year of study and two more locations will be selected for 1990 starts. The San Joaquin Valley Drainage program is in the planning phase and the four areas currently in detailed study will move into the planning phase in 1991. The Kesterson Reservoir presently is in the remediation phase.

Collectively, the completed reconnaissance studies have led to several general observations regarding irrigation-induced water quality problems. These observations include 1) Geologic sources of trace elements are important in determining where irrigation-induced water quality problems are likely to exist; 2) Variations in meteorological conditions of an area may affect the potential for irrigation-induced contamination problems; 3) The potential for irrigation-induced contamination appears enhanced in areas where internal drainage basin or sinks are present; 4) Selenium is the constituent of concern most frequently detected; and 5) Concentrations of trace constituents vary widely on a spatial basis.

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INTRODUCTION

For many years it has been documented that drainwater from irrigation projects has affected the quality of receiving streams or lakes. In most cases, increases only in total dissolved solids and some principal dissolved constituents such as sodium and chloride are noted and in many cases these increases are of limited magnitude. However, in 1983, after waterfowl deformities, reproductive failure, and mortalities were found at Kesterson Reservoir in California, the link was made between irrigation drainwater and elevated concentrations of selenium. Research determined that irrigation water infiltrated and mobilized selenium in soils on the west side of the San Joaquin Valley. The water was carried by tile drains to a canal and subsequently was used to augment water supplies at Kesterson Reservoir.

Because of the concern that problems related to selenium or other trace inorganic or organic constituents in irrigation drainwater might not be limited to the Kesterson Reservoir area, the Department of Interior (DOI) in 1985 began a program to see whether problems existed in western States at other Department constructed or managed irrigation projects, national wildlife refuges, or other wetland areas for which the Department has responsibilities under the Migratory Bird Treaty Act, the Endangered Species Act, or other legislation. In early 1986, the first nine reconnaissance studies under this program were begun.

STRUCTURE OF PROGRAM

The program started in 1985 in reaction to the problems at Kesterson and to widespread public interest. In December 1985, a task group of DOI scientists and administrators developed a management strategy for the program and identified several areas of concern. Nine reconnaissance studies were begun in 1986. The management strategy while limiting the program to DOI-managed areas, did not limit the program only to concerns regarding selenium but instead constructed the program to address contamination problems by major constituents, trace elements, radiochemical constituents, and pesticides.

As the program has evolved it has become a five-phase process. The five phases previously described by Deason (1986) are (1) Site Identification (2) Reconnaissance Investigations (3) Detailed Studies (4) Planning, and (5) Remediation. The first three study phases have been or currently are addressed by the program. Projects conducted under these 3 phases are carried out by field study teams comprised of scientists from the U.S. Geological Survey (USGS), the Fish and Wildlife Service (FWS) and the Bureau of Reclamation (BOR), or the Bureau of Indian Affairs. A USGS scientist heads each study team. The budget for the program is provided to the office of the Program Manager by the participating bureaus. Based on project study plans and budgets, the Program Manager distributes funding to the project teams.

PROGRAM PHASES

Site Identification

Phase 1 is site identification. This phase of the program is essentially complete. Site identification involved the examination of existing data from about 600 irrigation projects and major wildlife areas in those States including and west of a line from North Dakota to Texas. The purpose of the site-identification phase was to determine which, if any, sites are likely to have irrigation-induced water quality problems. Nearby projects were grouped into a total of about 200 areas and 2-3 page reports were prepared for these grouped areas by a DOI work group. The reports were evaluated by a Comprehensive Survey committee to determine which areas needed further study. Including the nine areas where reconnaissance studies were started in 1986, the committee identified a total of 20 sites in 13 States not including Kesterson and the San Joaquin Valley for reconnaissance investigations. Another 11 sites were identified for pre-reconnaissance (desk-audit) examination.

Desk-audit examinations are now complete. These studies have identified several more areas for which reconnaissance studies are being started in 1990 or will be started in 1991.

Reconnaissance Investigations

Phase 2 is reconnaissance investigations. These are field sampling studies designed to determine levels of potentially toxic constituents in the water sediment and biota of the study area. The studies are two years in duration. The original nine studies were carried out in 1986-1987 and reports are published for all nine studies. Another 10 studies were carried out in 1988-1989 and reports are now being prepared. One study is being conducted in 1989-1990. Locations of these past and current reconnaissance sites are given in Figure 1. Based on the desk audit studies, reconnaissance studies are being started at four other sites during 1990. These sites are the Humboldt Project in Nevada; the Navajo-Hammond-Fruitland-Hogback Projects in New Mexico; the Dolores-Ute Mountain Projects in Colorado; and the Owyhee-Vale Projects in Oregon-Idaho. Reconnaissance investigations will be started in future years as necessary.

Because of different hydrologic and geochemical conditions and unique ecological systems at each area, study designs have been somewhat different for each study area in terms of sampling schedules and biota sampled. However, the investigations are guided by a common protocol developed by the task group and the agencies involved, to increase comparability among the study areas. Sampling sites are determined by each study and the individual study teams, and samples for water, bottom sediment, and biota generally are collected before, during, and after the irrigation season for each study area. Samples from each media at the sampling site are analyzed for suites of major constituents and

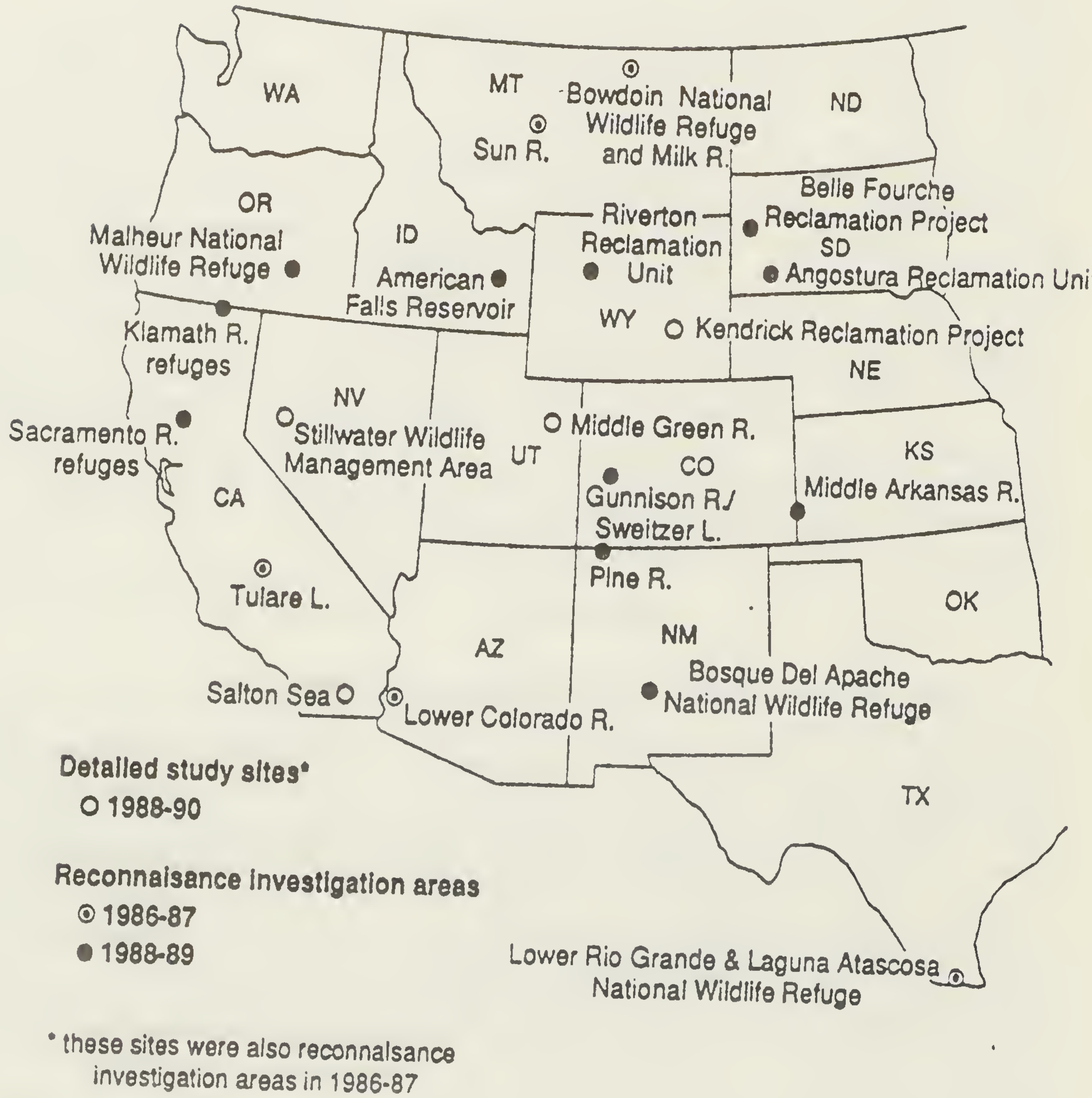

Figure 1. Location of study sites, Department of Interior Irrigation Drainage Program, 1986-1990. (from U.S. Geological Survey)

trace elements including arsenic, barium, boron, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, and zinc. In addition, pesticide and radiochemical analyses are performed at the discretion of project teams in response to the anticipated problems in their study areas.

In order to facilitate decision making regarding subsequent phases of the program, the DOI developed a set of guidelines to assist the field study teams in interpretation of data collected during the reconnaissance studies. The guidelines provided the study teams with information for making data comparisons and included standards and criteria promulgated by various organizations, geochemical baselines for trace elements from soils, baseline contaminants in fish from the FWS National Contaminant Biomonitoring Program, contaminant residues in wildlife from FWS, and baseline contaminants in water from the USGS National Water Quality Accounting Network program.

Detailed Studies

An analysis of the information from the first nine reconnaissance studies indicated that potentially serious irrigation drainage-related water quality problems existed in several areas. The task group determined that four of the study areas warranted Phase 3 detailed studies. Similar conditions were identified at a fifth area, Tulare Lake Bed in California. However, because of its location, further study in the Tulare Basin has been incorporated into the San Joaquin Valley Drainage Program. The purpose of detailed studies is to gather information necessary to identify and evaluate remediation alternatives. While reconnaissance studies are to study the location and amounts of potentially toxic constituents, detailed studies are indepth studies of the hydrology and biology of the area. Where reconnaissance studies are guided by a common protocol, detailed studies are tailored specifically to each individual area and include the identification of sources, transport mechanisms, and fate of potentially toxic constituents as well as food-chain studies and quantification of adverse effects. The four areas identified in 1988 for detailed study were:

Salton Sea, California
Stillwater, Nevada
Middle Green River, Utah
Kendrick, Wyoming

These detailed studies began in 1988 and will be completed in 1990. Elevated concentrations of several constituents in water, sediment, and biota were detected at each of the four study areas. Selenium was the principal constituent of concern in the Salton Sea, Middle Green River and Kendrick areas, while arsenic was the principal constituent of concern at Stillwater.

Two detailed study starts are planned for 1990. The areas will be determined in February 1990 based on the results of the 10 reconnaissance studies completed in 1989. Detailed studies will be started in future years as necessary.

Planning

Phase 4 is the planning phase and involves the development of coordinated plans of action for cleanup with appropriate Federal, State and local agencies. When Phase 2 reconnaissance studies indicate that potentially serious problems exist and that Phase 3 studies are called for, it generally implies that the final two phases of the program will be required at these sites. None of the westwide studies are at this phase but the four areas now in detailed studies will move into the planning phase in 1991. Although it is a different program, the equivalent of Phase 4 is underway for the San Joaquin Valley Drainage Program and is complete for Kesterson Reservoir.

Funding support for Phase 4 will be different than for Phases 1-3. Although interagency study teams probably will continue to develop remediation plans, funding will be provided by the bureaus that actually constructed projects or manage Federal lands in the affected areas. Funding will flow through the BOR for planning activities in 1991 for the four areas now in the detailed study phase.

Remediation

The final phase, Phase 5, is that of remediation. This involves the implementation of corrective actions developed during the Planning process. Although not specifically a part of the westwide programs, Kesterson Reservoir presently is in the remediations stage.

SUMMARY OF RESULTS

At the time of this writing, published reports are available for nine reconnaissance study areas: the lower Colorado River, Arizona-California (Radtke, et al. 1988); Tulare Lake, California (Schroeder, et al. 1988); Sun River, Montana (Knapton, et al. 1988); Milk River, Montana (Lambing, et al. 1988); Laguna Atascosa, Texas (Wells, et al. 1988); Middle Green River, Utah (Stephens et al. 1988); the Kendrick Project area, Wyoming (Peterson et al. 1988); Salton Sea area, California (Setmire et al. 1990); and the Stillwater area, Nevada (Hoffman et al. 1990).

Although a description of results from each reconnaissance area is beyond the scope of this paper, several general observations became apparent after these first nine reconnaissance investigations were complete (Deason, 1989; Sylvester et al. 1988). These observations are based collectively on the results of the completed reconnaissance studies and may generally be apropos in assessing concentrations of constituents in water, bottom sediment, and biota, associated with irrigation in all westwide areas.

First, a geologic source of trace elements is important in determining where problems of irrigation-induced contamination are likely to exist. For example, marine shales known to contain selenium and other trace elements are the source rocks for soils in the Kendrick Project area, the Middle Green River area and part of the Tulare Lake area. In each of these areas, selenium was found in water, sediment, and biota in concentrations that could cause harmful effects in wildlife. These concentrations appear to be directly related to geologic sources especially where the sources are pervasive and the selenium occurs in substantial quantities in the source rock.

Second, variations in meteorological conditions of an area may affect the potential for irrigation-induced contamination problems. Yearly variations in precipitation and streamflow may complicate the assessment of irrigation-induced contamination problems. For example, some areas, notably the Middle Green River, Lower Colorado, and Milk River had above average precipitation during the period of study. Generally, constituent concentrations were not at levels known to produce harmful effects in biota in the Milk River or Lower Colorado study areas. In these areas, the higher streamflow raised water levels in wildlife refuges and may have flushed some soluble salts from the wetlands. However, in the Middle Green area, although streamflows were greater and flushing may have taken place, some trace constituents, predominantly selenium, were found in elevated concentrations in all media. Deformed coot embryos were found by the study and reproductive declines were suspected. Therefore, it is postulated that the problems encountered were less severe than during period of normal or deficient streamflow.

Third, the potential for irrigation-induced contamination appears enhanced in areas where internal drainage basins or sinks are present. Closed watersheds or sinks occur in all those areas in which trace element concentrations justified detailed study with the possible exception of the Middle Green area. Generally, in the Tulare Lake, and Kendrick areas, selenium concentrations in biota were greatest in areas with no outlet or in ponds with little flow-through. Several trace constituents, notably arsenic, occur in elevated concentrations in the Stillwater area, an area with no external drainage. Even in areas like the Sun River, Milk River and Lower Colorado where trace constituents generally were not at levels that could result in harmful effects to wildlife, the greatest trace element concentrations detected were generally found in terminal drainages with no outlet, or in backwater or oxbows. The principal exception is in the Middle Green area. Concentrations of selenium that could result in adverse effects on wildlife reproduction were found in Stewart Lake and in ponds and wetlands at Ouray National Wildlife refuge. These are managed water bodies with inlets and outlets, for the most part flow-through systems.

Fourth, selenium is the constituent of concern most commonly detected at elevated levels throughout the nine studies. Although selenium was not the constituent of principal concern at Stillwater, it was detected there in elevated concentrations. At the other areas selected for detailed studies, selenium was the principal constituent of concern. At all the other areas where it did not occur at elevated concentrations, selenium was still present and was detected in all media.

Finally, concentrations of trace constituents were found to vary widely on a spatial basis in water, sediment, and biota in all study areas. This means that irrigation-induced contamination problems may be very site-specific. That is to say that problems may be quite severe on an extremely localized basis but may be less severe only a short distance away. Two conclusions may be inferred. First, irrigation-induced contamination problems may have a low level of relative significance on a regional basis. Second, the problems may be of relatively recent occurrence and depending on the hydrology may not have had time to be widely distributed spatially. The second statement may ultimately be borne out by the San Joaquin Valley experience where a major project has been in place for years and where contamination problems now exist over relatively large spatial areas. However, the distribution of contaminants may also be regulated in part by the size of the irrigation project, i.e., the amount of water distributed and the amount of return flow or drainage.

FUTURE OF THE PROGRAM

The National Irrigation Water-Quality Program is expected to continue several years into the future. During the 1990 fiscal year, one ongoing reconnaissance and four ongoing Phase 3 detailed studies will be completed. Four reconnaissance studies have been initiated in 1990 as a result of the completion of the Phase 1 comprehensive survey studies. Finally, two new Phase 3 detailed studies of three years duration will be started as an outgrowth of the ten Phase 2 studies just completed.

The outlook is much the same for 1991. The four Phase 2 studies started in 1990 will be completed. The two Phase 3 studies started in 1990 will be in their second year. It is expected that three additional Phase 2 reconnaissance studies of two years duration and two more Phase 3 detailed studies of 3 years duration will be started. The principal change for 1991 is that the Phase 4 planning process will begin for the 4 detailed studies completed in 1990.

The completion of the ten Phase 2 reconnaissance studies in 1989, coupled with the results of the nine previously completed studies and the San Joaquin Valley and Kesterson studies constitute the first interdisciplinary evaluation of the magnitude and extent of irrigation-induced contamination problems in Western States. Our knowledge base concerning source, mobilization, transport, fate, and impacts of potentially toxic constituents in irrigation drainwater will continue to expand as we continue to work toward the ultimate resolution of these problems.

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DATA ADEQUACY: CHALLENGE OF THE 1990'S

Adam A. Sokoloski[1]

ABSTRACT

The Bureau of Land Management (BLM) is responsible for the multiple-use management of the public lands in a manner that provides for a variety of often competing uses. The management and regulation of mining activity and the oversight of reclamation of lands disturbed by mining are two of the most important responsibilities that BLM undertakes. BLM must have adequate amounts of valid information on the effects of each use upon the land it manages and on other uses. The collection, storage, accessibility, transferability, adequacy, and validity of data is a major challenge of the 1990's for BLM.

BLM is developing an automated Land Information System (LIS) that will consist of a series of data bases containing resource, land status, and land survey data, and geographic and cultural features organized in a manner that permits these data to be displayed and manipulated for specific geographic areas. This system will also be accessible to other government entities and the public. BLM is developing minimum standards both for the quality of data collected and used for resource management and for the entry and manipulation of these data in the LIS. A prime example of data quality standards are BLM's Coal Leasing Data Adequacy Standards and the regional data adequacy standards developed by the regional coal teams. Minimum standards are also being established for the collection, analysis, and use of data through inspection and enforcement (I&E) requirements for oil and gas and other leasable minerals, and the emerging I&E program for locatable minerals. BLM is concurrently establishing data entry standards and is addressing the issue of access to and use of these data.

In the 1990's, BLM will draw all of these efforts together by testing interim systems and developing the target systems with the goal of implementing LIS in 1993.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

SOIL, SPOIL AND WASTE MATERIALS ANALYSES AND DATA INTERPRETATION

Patrick Sullivan[1] and Joe Morotti[1]

ABSTRACT

Because of the variability in analytical results reported for coal overburden and topsoil, a greater degree of quality assurance/quality control (QA/QC) is required for these analyses. With the proposed development of models to predict post-mining crop productivity and water quality, reliable analytical data are critical.

Given current unsuitability criteria as an example, past OSM round-robin data are summarized for each criteria and method of analysis. Sources of method variability are suggested along with a proposed protocol to establish a suite of chemical and mineralogical values. Examples of intra-laboratory variability for inorganic and organic analyses performed by laboratories that are in the U.S. EPA Contract Laboratory Program are illustrated.

One method that can be used to assist in improving QA/QC is the use of reference samples by laboratories that provide overburden and topsoil analyses. The concept of reference samples and their use for interpretation of laboratory performance is presented.

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PLANNING, REHABILITATION AND TREATMENT OF DISTURBED LANDS
BILLINGS SYMPOSIUM, 1990

ECOSYSTEMS RESTORATION ON COPPER TAILINGS IN THE SOUTHWEST

S.A. Bengson

ABSTRACT

For well over 20 years Asarco has been pioneering and developing innovative and cost-effective techniques for restoration of ecosystems on copper tailings in southern Arizona. These techniques are primarily designed to stabilize the tailings vegetatively rather than chemically or physically. The tailings are highly erodible and must be stabilized to control blowing dust and erosion. Coupled with the extremely harsh and arid environment of the Southwest are the adversities of these tailings. This makes establishment of vegetation on these tailings a challenging and ecologically interesting task.

The tailings themselves are the extremely fine ground rock residues from the milling process that extracts the finely disseminated copper from the ore. Besides being totally inert with absolutely no soil characteristics whatsoever these tailings are highly erodible and have adversities associated with temperature extremes, pH, salinity, steep slopes, lack of nutrients and fertility, texture, drought, and surface conditions impeding the establishment of vegetation.

The main premise of Asarco's vegetative stabilization program is to establish a permanent, productive ecosystem. By establishing a viable self-sustaining ecosystem on the tailings a vegetative cover will be able to stabilize the tailings for the future. To do otherwise would jeopardize the long-term requirements for stabilization, or necessitate perpetual maintenance and upkeep. Also, by restoring a viable ecosystem on the tailings, the mine site is returned to productive future uses.

Agronomist-Mined Land Reclamation, ASARCO Incorporated
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Arizona has been the major copper producing region of the U.S. for well over half a century. In 1988 Arizona produced nearly 860,000 tons of copper, for approximately 2/3 of this nation's newly mined domestic copper supply (Arizona Mining Association 1988). Asarco has been a proud part of this record for more than 4 decades and continues to increase its productive capacity.

Copper mining in the Southwest is predominantly accomplished by open-pit methods. This involves extensive excavation of 100 feet or more of surface overburden to expose the ore body. This non ore bearing material must be deposited in large overburden heaps. With grades ranging from 0.3% to 0.7% copper the ore must be milled by grinding to the consistency of very fine sand and the fine copper particles floated off to produce a concentrate containing 27% to 30% copper. The concentrate is shipped to a smelter. This milling procedure produces vast amounts of tailings, or the finely ground rock materials which are pumped as a slurry to large lagoons, or tailing impoundments. As the tailings settle out the water is recycled.

In Arizona only about 0.26% of the land area, or approximately 193,000 acres has been impacted by mining (Arizona Mining Association 1979). Although these materials are not hazardous, wind can cause dusting and water erosion can make them unsightly. These problems are greatly intensified where urban expansion encroaches upon the mine site. The public then requires a more natural and aesthetic vista, stabilization of the erosion, and return of the land to a productive and naturally scenic condition. Therefore vegetative stabilization of these tailings is becoming an integral part of mining.

Since the mid 1960's, Asarco has been developing techniques to vegetatively stabilize these materials and return the sites to a productive capacity. Beginning in 1973, Asarco initiated an intensive professional revegetation program to investigate the problems and develop sound economic revegetation techniques. Working on revegetation of tailings and overburden at 3 mine sites in southern Arizona, Asarco has successfully revegetated over 170 acres. Asarco is continuing to develop new and more cost-effective techniques to vegetatively stabilize these tailings.

There are numerous complex and unique problems facing tailings revegetation in southern Arizona. Although the basic over-riding problem involves aridity, each site will have its own unique set of environmental problems to overcome. Soils, aspect, slope, etc. can make major differences in the final make-up of the ecosystem. Rainfall in this region can vary from as little as 3 inches/year to as high as 18 inches/year. However, annual evaporation often exceeds 115 inches or more (see Graphs). Other problems include pH extremes (both acidic and alkaline); complex and difficult soil textural problems; serious deficiencies or a total lack of essential nutrients, organics, and necessary soil mycorrhizae; complex salinity,

pyritic, or sulfide crusting problems; excessive concentrations of phytotoxic or growth inhibiting heavy metals and salts; extremely elevated surface temperatures and high albedos which can literally bake emerging vegetation; steep unstable slopes (often 1:1.5 angle of repose); and extreme erosive characteristics which can severely damage establishing vegetation by burial or sandblasting.

The successful revegetation of any site must first start with the proper site preparation techniques. These techniques must be carefully selected for each individual site to prepare the site for seeding or planting to maximize plant survival. These techniques can vary from simple surface scarification to extremely complex "topsoiling" and regrading to enhance seed germination and plant survival. At Asarco a "Holistic Mined Land Reclamation Model" (HMLR) is used to guide the reclamation work to the desired goal of creating a permanent, self sustaining, productive ecosystem.

Going through the HMLR Model (see Chart) the "ecosystem blocks" are the very foundation which supports a viable and productive land-use description. Understanding some of these basic principles of succession will help to develop a sound "holistic" approach to mined-land reclamation. Further on in the HMLR Model, the "tools" and "guidelines" are merely the methodologies and aspects to be considered for use to develop and build the "Ecosystem Blocks". Each "tool" is evaluated and monitored continually using the various "guidelines". If a "tool" fails to meet all the criteria to reach the desired goal, it is modified or discontinued. Each site is variable and as the ecosystem evolves conditions will change. This HMLR Model must be continually monitored to study the reactions and modified as needed for the changing conditions at each site.

HMLR is a concept for successful ecosystem restoration. It may be a new way to approach the old problem of how to ecologically reclaim tailings to a productive land-use. As reclamation scientists we separated reclamation into topsoil, plant species, spoil amendments, seeding techniques, etc., without looking at reclamation of the ecosystem as a "whole". The resulting tailings reclamation may be, in many instances, simplistic landscaping. Some of the very best "ecological mine reclamation" may be what nature has done on abandoned tailings that were never touched by a reclamationist.

At Asarco the tailings revegetation usually begins by "capping" the tailings with a thin cover of soil material. The soil material used is salvaged from areas that are to be covered with non-bearing materials, or is sometimes stockpiled from pit excavation. Most tailings only require a very thin "cap" of soil, perhaps 2 to 6 inches or less. Often, just mixing a small amount of soil into the tailings is sufficient for successful revegetation. This "capping" is only practical however, at sites where adequate soil materials are readily available. It is totally impractical to "import" soil, and

would only leave a scar where the soil was excavated that would have to be revegetated later.

Looking at tailings as an ecologically primitive soil, techniques of incorporating organics and other soil amendments into the tailings have been successfully utilized. These techniques basically involve adding organic waste materials to ameliorate the surface environment to initiate vegetation and then cultivating this vegetation back into the site to build up a suitable soil medium. Sewage sludge and livestock manures are just two examples of organic wastes that have been proven successful. The organics can moderate pH extremes, improve moisture regimes, help to develop soil structure, and surely enhance the nutrient and mycorrhizae levels. Good stands of grasses and shrubs have been established with this technique. Ecologically speaking, this technique can be quite advantageous. The impoverished tailings are not simply "buried" with topsoil. The site is actually stabilized by building its own soil. However, this technique does have limitations. It is quite difficult, if not entirely impossible, to use this technique on steep slopes. Also this technique may require several years of intensive cultivation to be successful. There is also the availability of suitable organic materials to be considered. Some sewage sludges can "contaminate" the site. Many factors must be considered when selecting which site preparation technique may be best for any given site.

The next step in a professional revegetation program is the selection of the plant species best suited for the specific site. This process is quite complex and can be very critical. It is essential to select species that are adaptable to the specific environmental conditions found at the site and, of course, species that fit the future desired objectives. Asarco's objectives are to stabilize the sites with a viable productive ecosystem equal to or greater than that which existed prior to mining disturbance. Plant species are selected based upon their adaptability to the specific site conditions, physiological characteristics for stabilization, wildlife or livestock habitat values, and aesthetics. For a desert grassland ecosystem, the primary species for revegetation is a mixture of grasses with a scattered overstory of shrubs and trees. The principle major grass species used are: Lehman's lovegrass (Eragrostis lehmanniana), blue panicgrass (Panicum antidotale), bermuda grass (Cynodon dactylon), and bufflegrass (Cenchrus ciliare). Associated with these grasses are several shrub and tree species to diversify the plant community, give it a more natural appearance and to enhance the wildlife cover and browse values. The primary tree and shrub species include: eucalyptus (Eucalyptus sp.), saltbushes (Atriplex sp's), mesquite (Prosopis sp's), paloverdes (Cercidium sp's & Parkinsonia aculeata), fairyduster (Calliandra eriophylla), brittle bush (Encelia farinosa), and ruby sheepbush (Enchiliana tomentosa). Variations of this composition would include some legumes (Melilotus sp's & Medicago sp's), acacias (Acacia sp's), sagebrush (Artemesia sp's), hopseed bush

(Dodonea viscosa), and saltcedars (Tamarix pentandra and aphylla). For a desert shrub plant community species would include Australian accacia (Acacia redolense & nobilis), creosote (Larrea tridentata), desert broom (Baccharis sarothroides), and several various saltbushes (Atriplex sp's). Many "exotic" species are selected because they are better adapted to the particular site environment, or other desirable characteristics. Many "native" species may not be available in sufficient quantities from plant material sources for large scale revegetation. Another problem with many of the "natives" is that the plant physiologies and germination requirements are not well known and agronomic techniques for germination, planting, and cultivation have not been developed. A good revegetation program will take the natural ecosystem into account and develop a species composition that will blend in with, and complement, the natural plant community. The main objective of the revegetation program is to stabilize the site. Once the site has been properly stabilized then natural succession can occur and eventually a more "native" ecosystem will become established. It is often extremely difficult, if not altogether impossible, to stabilize harsh man-made sites such as tailings with "natives" only. The "natives" are generally not well adapted to the unnatural "man-made" soils and environments encountered and, consequently, they often fail. This leaves the site unstable so that natural ecosystems can never become established or will take much longer to eventually evolve.

Once the desired species composition has been selected the proper techniques to establish the vegetation must be carefully selected. Basically there are two techniques to establish vegetation: direct seeding or hand planting of seedlings. Direct seeding is probably the most practical and preferred technique. Here the primary concerns involve the total amount of seed required for the desired vegetative density as determined by seed purity and germination; good soil/seed contact; and the various specific germination requirements of each species. Often the seed of various species will require different treatments for germination and may preclude their use in a seed mix.

The two basic methods of direct seeding are broadcast seeding and drill seeding. Drill seeding is the preferred method as this technique actually places the seed in the soil at the correct depth for that species, spaces the seed correctly for desired plant density, and then adequately covers the seed with soil to reduce predation by scavenging insects and wildlife. Broadcast seeding simple disperses the seed out over the soil surface. Here scarification of the soil surface is critical to assure that the seed gets down into the soil. Of course depth of seed in the soil and adequate soil coverage are totally uncontrolled. Hence, with broadcast seeding, the recommended seeding rates for any given species should be doubled or tripled in many cases.

Because of the intricate problems and uncertainties of ultimate vegetative establishment with direct seeding; hand

planting seedlings can offer several advantages. Of course the major drawback to this technique are the initial high costs of plant materials and intensive labor. However, the seedling planted has a developed root system and plant vigor that will enhance its chances of survival. Of prime importance to both direct seeding and hand planting is that the plant/seed source of any given species be selected from local sources. Small genetic variances will dictate superior varieties. Even species variation from one elevation or one aspect to another may make the critical difference in survival and ultimate revegetation success.

Asarco's experience in southern Arizona has shown that a combination of both direct seeding and hand planting techniques is the most successful. Because of the steep slopes encountered (1.5:1) hydroseeding is the most practical technique for overall revegetation. This technique mixes seeds, any fertilizers or amendments deemed necessary, and a hydromulch material into a slurry that is then sprayed onto the slopes. This is an exceptionally effective method to evenly disperse and hold the seed on these steep slopes.

Although this technique has proven to be very effective and practical, it is not without some drawbacks. There are problems such as seed damage by the hydroseeder pumps, the adverse effects of prolonged soaking on seed germination, and the possibility of seed being suspended away from the soil surface in a heavy slurry application of hydromulch. There is also some problem with certain hydromulches actually impeding germination and seedling establishment.

Techniques developed over time by Asarco have alleviated many of these problems. To reduce damage to the seed by the hydroseeder pumps or prolonged soaking, the seed is added to the slurry last, usually just before actual hydroseeding. Generally the seed is only in the mixing tank long enough to become thoroughly mixed before being sprayed out (5 to 10 minutes total). To improve the hydroseeding Asarco uses the "2-step" technique. This involves mixing the seed first with a minimal amount of mulch material - usually 200 lbs. per acre or less - to help hold the seed on the slope; a second, heavier application of mulch is then applied on top of the seed - 1800 lbs. per acre or more. Also there are many inexpensive and effective mulch substitutes that make a suitable slurry for the first step hydroseeding. These include seed screenings and chaff, sawdust, excelsior trash, and other fine organic materials. Using seed screenings with the seed mix has proven to be exceptionally advantageous. Natural grass, or prairie hay, at 2 tons per acre, with a tackifier can be a superior mulch to improve vegetative establishment. However, without supplemental irrigation there is a very serious question of this hay mulch actually intercepting and absorbing rainfall thereby depriving the seed and soil of moisture required for germination during periods of below-normal rainfall.

Hand planting trees and shrubs has been most successful when utilizing nursery grown containerized planting materials. Past experience has proven that bare-root transplants, or trying to transplant native plants from undisturbed natural areas are unsuccessful. Most desert species have extensive root systems or taproots that cannot withstand the shock of being bare-rooted or transplanted. The most practical containerized planting stock are gallon-sized plants. By adopting a "tubling" container, approximately 3 inches square by 14 inches deep, costs can be effectively reduced and superior plants produced.

In the semi-arid environments supplemental irrigation for initial seed germination and plant establishment is essential to assure revegetation success. This is especially true of hydroseeded sites as the seed has already been wetted initially and many seeds may have already initiated germination and will require subsequent moisture for survival. Although there is a great deal of controversy over the use of irrigation, Asarco has found that supplemental irrigation is necessary to assure a quality revegetation program that is dependable. Rainfall is too sporadic and undependable, resulting in failure of the revegetation program. The supplemental irrigation is designed to provide the necessary moisture only for the initial germination and establishment of the plants. Generally the irrigation can be totally withdrawn after the first growing season. Supplemental irrigation is vital to establishing vegetation on steep slopes as rainfall is rapidly drained off thereby effectively reducing actual rainfall by as much as one-half or more before the establishing plants can utilize the moisture.

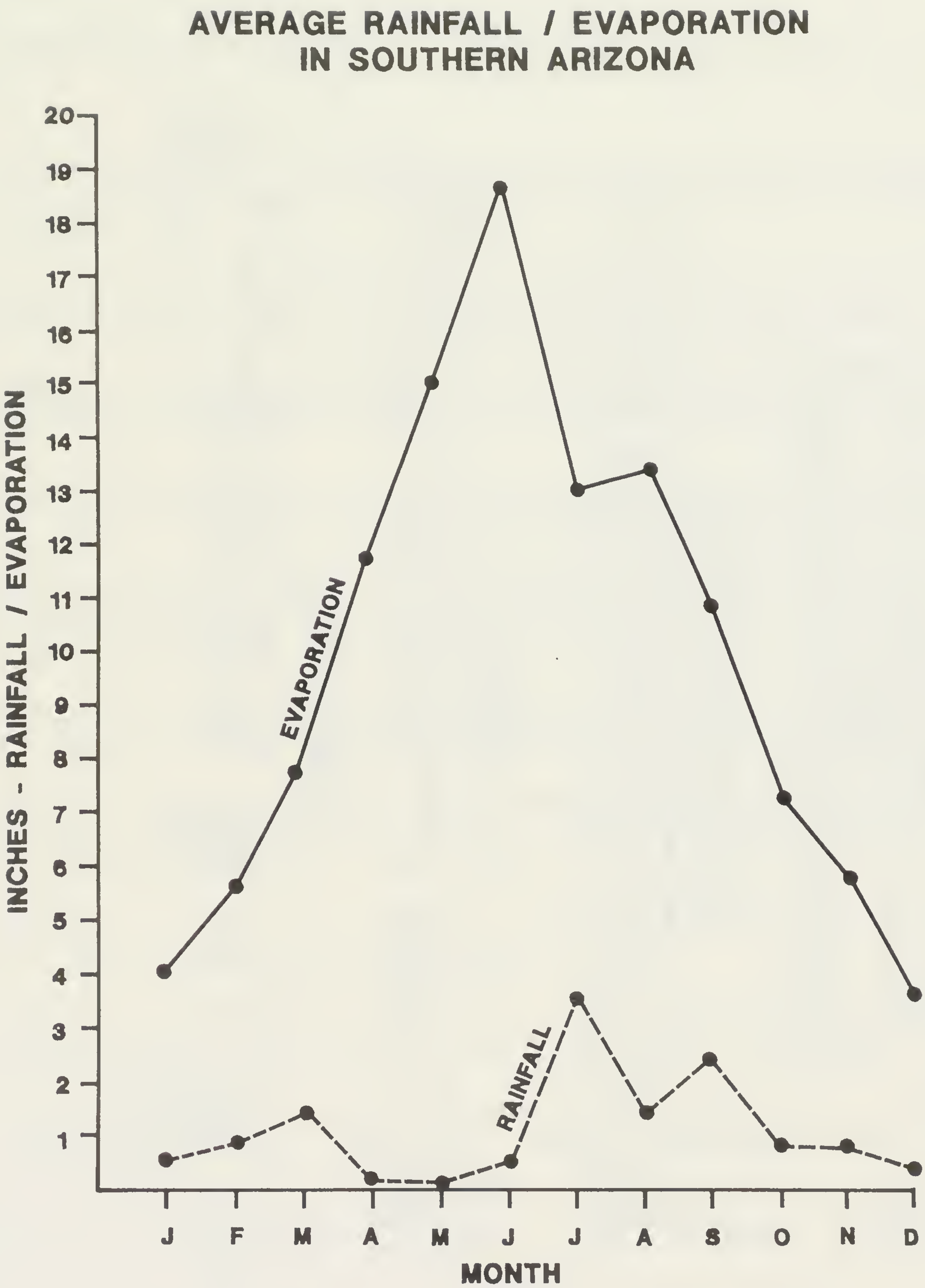
Basically there are two irrigation techniques available: sprinkler and drip irrigation. Sprinkler irrigation is the dominate technique used for supplemental irrigation and is best used to establish grasses and herbaceous ground cover. Here sprinkler systems are designed and operated to simulate 1/4 - 1/2 inch rainfall events over a 2-3 hour period. This irrigation schedule is then gradually reduced as the plants grow to size and become established. By utilizing this technique the sites may be seeded when air temperatures are optimal for seed germination. The main drawback to sprinkler irrigation is the large volumes of water and relatively high operating pressures required. This supply of water and the necessary facilities to deliver this water to the site may not be possible.

Drip irrigation requires much less water and much lower operating pressures than sprinkler irrigation. With drip irrigation, water is delivered to each individual plant via a drip emitter. Each emitter delivers a precise amount of water to each plant - generally 1 gallon/hour. Irrigation schedules require 8 or more hours to adequately irrigate the plants. This technique provides very deep watering for optimum root development, but does not provide sufficient surface moisture for widespread seed germination. The area of surface moisture around each emitter generally is limited

to less than 1 foot. The major drawback with drip irrigation, other than not being able to establish dense vegetation or ground cover, is its labor intensive nature. It is essential that all water used in drip irrigation be filtered. Even then the drip emitters have a tendency to plug-up with algae, salts and other contaminants that get into the system beyond the filter. These require daily maintenance. In addition wildlife find the plastic drip hose irresistible to chew on and cause numerous leaks requiring daily repair. Another drawback is that the spatial arrangement of the plantings provide a very unnatural linear appearance along the driplines. Also, because the plants are widely spaced, wildlife browsing dramatically impacts the revegetation program.

Today newer technology is emerging utilizing "micro-sprinklers" which incorporates the best of both sprinkler irrigation and drip irrigation. Here low volume, low pressure water systems can be utilized and small sprinklers provide adequate surface moisture for seed germination. This technology may not necessarily be a panacea for all problems, but when properly designed and implemented it can resolve many of the problems of revegetation of harsh sites in an arid environment.

Revegetation of tailings can be successful, even in extremely arid environments. The main ingredient required is dedication and professional competency to develop and implement the proper techniques. Asarco has been able to innovate and create the necessary techniques needed to answer the many and varied revegetation problems facing tailings reclamation. Applying new irrigation techniques, irrigation scheduling, hydroseeding techniques, plant species selection, mycorrhizae development, and other new technologies as they become available have made Asarco a recognized leader in revegetation of mine wastes and other problem sites in the Southwest.


AVERAGE RAINFALL / EVAPORATION
IN SOUTHERN ARIZONA
INCHES - RAINFALL / EVAPORATION
20
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1
EVAPORATION
RAINFALL
J F M A M J J A S O N D
MONTH

HOLISTIC MINED LAND RECLAMATION MODEL

GOAL
PRODUCTIVE LAND USE DESCRIPTION

ECOSYSTEM BLOCKS

Succession | Water Cycle | Mineral Cycle | Energy Flow

TOOLS

$
ECONOMIC
INPUTS
MONEY
MANHOURS

(REVEGETATION TECHNIQUES · SOILS · MYCORRHIZAE & AMENDMENTS · ANIMAL EFFECTS · TECHNOLOGY & RESEARCH)

P
PEOPLE
HUMAN
CREATIVITY

GUIDELINES

- Whole Ecosystem
- Sociological Aspects: Human Resources, Skills, Organization
- Weak Link
- Cause & Effect
- Economic Reaction: Gross, Marginal Gains
- Biological plan & Control
- Time Growth Rate
- Site Productivity Feritily
- Grazing Browsing Effects
- Plant Response
- Flexibility
- $: Plan, Monitor, Control, Replan

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Planning, Rehabilitation, and Treatment of Disturbed Lands
Billings Symposium, 1990

COLUMN LEACH STUDY I: HEAVY METAL DISSOLUTION CHARACTERISTICS FROM SELECTED COPPER MINE TAILINGS

Richard D. Doepker[1] and William K. O'Connor[2]

*** ABSTRACT

Mill tailings collected from seven copper mine mill sites in the western United States were examined by researchers from the Bureau of Mines for metal dissolution properties using a column leaching procedure involving a formulated "western rain" leachant. Studies investigated effects of height of waste column, wet/dry cycle, and maximum leachability of waste tailings. Further studies on selected samples indicated that treatment of acid-producing tailings with chemical stabilizers such as phosphates and carbonates did not greatly affect mobilization of heavy metals leached from these samples. Increased metal mobilization from unsaturated columns was often associated with decreased leachate pH and increased sulfate production, but was not observed in all samples examined. Results from these and other studies suggest that the driving force for metal dissolution and/or acid formation in unsaturated mine tailings is the oxidation of metal sulfides by atmospheric oxygen. The maintenance of tailings at or near saturation or the exclusion of atmospheric oxygen appear to produce leachates of nearly constant to slowly decreasing metal concentrations with each subsequent leaching.

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INTRODUCTION

The rapid release of acid and metals from mining wastes by natural leaching processes presents a great potential threat for the contamination of groundwater and is perhaps the most serious impact mining can have on the environment. Although there are many methods designed to predict the amount of acid mine drainage (Ferguson 1985; Ferguson and Erickson 1987) none are completely successful. Characteristics of the waste, leachate percolation rates and pathways, and availability of atmospheric oxygen may greatly affect metal dissolution and acid formation. When mine wastes are disposed of on the surface, conditions are especially favorable to accelerated oxidation of pyrite and subsequent production of acid (Bainbridge et al. 1980).

In previous studies (Doepker 1988, 1989) selected mine tailings were examined to determine the parameters that affect the dissolution and transport of metal ions in mine tailings. It was found that metal dissolution and/or acid formation increased in unsaturated tailings, presumably as a result of atmospheric oxidation of sulfide minerals (Nordstrom 1982; Nordstrom et al. 1979). It was further demonstrated that leachate metal concentrations were independent of residence time if the columns were maintained at or near saturation. However, these studies all involved basic tailings, that is, tailings that produced basic leachates.

The purpose of the present study is to extend investigations to those tailings that produce acid leachate and to relate leachate concentrations to parameters such as type of metal mined, mineralogy, element composition, etc. This report describes results of approximately 2 years of tests on tailings collected from western copper mines.

MATERIALS AND METHODS

The copper mine tailings were obtained from seven different sites. Characteristics of each of these tailings samples are described below.

Gold-Copper Mine Tailings, Washington

A composite sample of tailings as formulated from samples taken at three locations within a main tailings containment area was used in this study. Iron phases dominate the oxide fraction of the tailings and include magnetite (Fe_3O_4), hematite (Fe_2O_3), and goethite ($FeO(OH)$). The major gangue constituent is quartz (SiO_2). The sulfide fraction consists of pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and rare chalcocite (Cu_2S). Pyrite is abundant and generally occurs as liberated grains, but it is also locked with quartz gangue. Grain size for the pyrite averages 10-20 microns. Chalcopyrite is significantly finer grained (5-10 microns) than the pyrite, and is virtually always locked with gangue quartz. The abbreviated results of the "maximum leachability assay" (a nondestructive, mixed HCl-HNO_3 assay) (Kuryk et al. 1985) for these and all tailings studied in this investigation are given in table 1.

Copper Mine A Tailings, Montana

One large sample (approximately 100 lb) of tailings was used in all studies discussed in this report. Abundant free pyrite is the most distinguishing feature of these tailings. Magnetite is present in relatively significant amounts, as is ilmenite ($FeTiO_3$). Chalcopyrite occurs in minor amounts, usually locked with gangue particles. Gangue is predominantly quartz and orthoclase (potassium feldspar, $KAlSi_3O_8$). Several rare but

Table 1.--Assay of maximum leachable concentrations.

Sample	Depth, in	Elements, pct										
		Al	Ca	Cu	Fe	K	Mg	Mn	Na	Pb	S	Zn
Gold-copper mine[1]........		0.35	0.06	0.11	1.01	0.06	0.18	0.00	0.01	0.00	1.00	0.07
Copper mine A[2]..		.54	.45	.07	1.19	.32	.45	.01	.02	.01	1.48	.04
Copper mine B...	0-6	.84	.83	.04	1.05	.74	1.14	.01	.08	0	.79	0
	6-12	.63	.99	.03	1.04	.51	.86	.01	.05	0	.98	0
Copper mine C[2]..		.01	.02	.14	.45	.04	.01	.01	.02	.05	.32	.17
Copper mine D...	0-6	.09	.11	.16	.11	.08	.07	.01	.01	0	.26	0
	6-12	.09	.09	.07	.1	.07	.07	.01	.01	0	.25	0
Copper mine E:												
Hole 1........	0-6	.25	.17	.04	1.1	.32	.23	.02	.03	.02	.97	.01
	6-12	.20	.13	.03	.84	.26	.19	.01	.02	.02	.73	.01
Hole 2........	0-6	.34	.24	.13	1.17	.39	.29	.03	.06	.02	1.05	.02
	6-12	.37	.24	.10	1.21	.38	.28	.02	.03	.02	.97	.01
Copper mine F:												
Hole 1........	0-6	.42	1.06	0	.95	.29	.45	.02	.03	0	.86	.01
	6-12	.40	.97	.01	.85	.28	.43	.02	.02	0	.64	0
Hole 2........	0-6	.53	1.05	.01	1.09	.37	.56	.02	.03	0	.69	.01
	6-12	.46	.94	.01	.99	.33	.49	.02	.02	0	.79	0

[1]Composite sample, no depth recorded.

[2]No depth recorded.

Table 2.--Residence time effect on column leachate concentrations, wet/dry cycle, copper mine A tailings.

Residence time, days	pH	SO_4[1] mg/L	Element, mg/L										
			Al	Ca	Cu	Fe	K	Mg	Mn	Na	Pb	S[2]	Zn
7													
Sat...........	3.05	1,830	13.7	604	25.9	12.9	0.6	41.6	2.1	0.83	.1	647	6.45
Unsat.........	3.08	1,850	13.9	607	26.9	4.17	.5	48.8	2.28	.93	.1	695	7.18
14													
Sat...........	3.26	1,850	11.0	566	30.4	11.5	1.2	46	3.75	.97	.02	720	7.86
Unsat.........	2.89	2,000	24.5	612	52.9	3.88	1.5	52.3	3.22	1.06	.04	690	9.8
21													
Sat...........	3.43	1,890	12.4	592	35.2	16.1	1.1	49.3	2.47	1.10	0	656	8.4
Unsat.........	3.25	2,060	22	511	49.2	7.38	1.4	54.9	2.85	1.49	.11	692	9.21
28													
Sat...........	3.28	1,840	13.7	566	36.4	6.39	.7	40.8	2.3	1.32	.12	653	6.98
Unsat.........	2.62	2,400	54.5	579	77.4	14.3	2.7	58.2	3.24	2.01	.1	859	11.5
35													
Sat...........	2.93	1,880	16.8	567	29.7	11.5	.4	43.8	2.60	1.48	.1	670	8.62
Unsat.........	2.47	2,470	78.9	576	92.6	17.4	2.2	65.2	4.24	2.23	.12	910	12.5
43													
Sat...........	3.03	1,890	17.9	578	30.5	13.6	.5	40.8	1.97	1.53	.07	664	9.17
Unsat.........	2.54	2,640	74.1	545	78.7	15.1	2.2	59.2	3.61	2.12	.05	839	11.4
49													
Sat...........	3.07	1,900	16.4	619	32	20.9	.4	41.5	2.13	1.45	.13	576	9.61
Unsat.........	2.49	2,800	106	606	114	20.2	1.6	83	4.8	2.57	.11	958	16.7
56													
Sat...........	2.90	1,900	17.9	630	31.5	26.5	.4	41.9	2.58	1.36	.14	655	11.3
Unsat.........	2.68	2,640	83.8	620	118	15.5	1.4	82.7	2.92	2.69	.12	980	14.1

[1]Analysis with ion chromatograph.

[2]Analysis with Plasma II ICP spectrometer.

interesting minerals were also identified, including several grains of an iron-zinc silicate, pyromorphite [$(PbCl)Pb_4(PO_4)$], and finally, a lead-copper-antimony phase identified as either bournonite ($2PbS.Cu2S.Sb_2S_3$) or lead-bearing tetrahedrite ($3Cu_2S.Sb_2S$).

Copper Mine B Tailings, Utah

Two grab samples at the surface (0 to 6 in and 6 to 12 in deep) of these tailings were taken. The chemical compositions of these two samples are very similar (table 1). Mineralogical analyses show that these tailings contain more orthoclase than quartz. The sulfide fraction consists essentially of pyrite and chalcopyrite. As with copper mine A tailings, much of the pyrite is liberated, while the chalcopyrite is almost always locked with the quartz or feldspar gangue.

Copper Mine C Tailings, Montana

A single, 15-lb grab sample of copper mine C tailings was obtained, air-dried, and stored in a plastic bag. These tailings were used in two test protocols. Of interest is that the chemical composition of mine C tailings (table 1) differs from mine A tailings, even though the origins of both are in the same mining district. The gangue in mine C tailings is predominantly quartz, the majority of the grains are whole, and there are no major intergrowths. Iron oxide (magnetite) and hematite are relatively abundant. Pyrite is present, but is not as abundant as in copper mine A tailings. Sphalerite (ZnS) occurs as both liberated and locked grains (10-20 microns). Although sphalerite can not be considered a major constituent in the sample, its abundance is significantly higher in these tailings than in any of the others discussed in this report. Many of the quartz grains are rimmed with a combination of iron and potassium silicate (K_2SiO_3), probably feldspar with iron sulfide inclusions. The iron sulfide (most likely pyrite) has been oxidized, forming a coating on the rim of the original grain. Barite ($BaSO_4$) occurs in minor amounts, but its presence confirms the presence of sulfates in the tailings. Galena (PbS) and wolframite [$(Fe,Mn)WO_4$] were identified as well.

Copper Mine D Tailings, Arizona

Samples of these tailings were collected at 0 to 6 in and 6 to 12 in below the surface, analyzed, and used in a standardized test protocol. These Arizona tailings are similar to tailings from copper mines A and B in composition of the gangue, predominantly quartz and potassium feldspar. However, several other mineral phases distinguish these tailings from the others. Most of the copper in the tailings occurs in the form of chalcocite locked with quartz and feldspar grains, although chalcopyrite occurs in lesser quantities. Several iron minerals are present in the tailings, including pyrite, magnetite, hematite, and ilmenite.

Copper Mine E Tailings, Arizona

Four samples were taken from this mine-mill site at two locations in a large tailings impoundment. Samples were taken at 0 to 6 in and 6 to 12 in below the surface and subjected to a test protocol. These tailings contain the same phases as previously described for the other three Arizona samples. Quartz and orthoclase gangue predominate, and relatively abundant titanium-bearing iron oxides (magnetite, hematite) and titanium oxides (ilmenite, rutile [TiO_2]) are present.

Perhaps the major distinction of these tailings is the relatively abundant chalcopyrite, which occurs both as inclusions in the gangue and as liberated grains. The copper analyses for the three Arizona tailings support the determination made in the characterization study. Copper content is significantly higher in copper mine D and E tailings as compared to mine F tailings (table 1). However, the major copper phase differs between the mine D and E tailings: chalcocite (20% sulfur) at mine D and chalcopyrite (35% sulfur with 30% iron) at mine E.

Copper Mine F Tailings, Arizona

The last set of tailings were collected at 0 to 6 and 6 to 12 in below the surface from two locations within a single tailings impoundment. It should be noted that all three Arizona operations are in the same geological region. Quartz and orthoclase gangue predominates. Pyrite and chalcopyrite are the major sulfides present, but no chalcocite was found in these tailings. Several oxide phases were found, including titanium-bearing magnetite and hematite, ilmenite, and rutile. Several zircon grains were identified, as well as apatite [$(CaF)Ca_4(PO_4)_3$]. Barite and anhydrite ($CaSO_4$) occur in compound grains, some including celestite ($SrSO_4$).

The tailings samples used for all experiments were air dried in the laboratory, crushed manually to break up agglomerated particles formed during drying, blended, and stored in closed plastic containers.

CHEMICALS

All chemicals in this study were commercially available, analytical-grade reagents (A.R. grade) used without further purification. The deionized water was produced in the laboratory through distillation (Barnstead glass still)[4] and then deionized with a Barnstead NANOpure II Demineralizer (18.3 Mohm/cm). Leachant solutions were prepared by standard analytical techniques using only A.R. grade chemicals and prepared deionized water. They were then stored in carboys until used. Simulated western rain was prepared as described by Bainbridge et al. (1980).

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

COLUMN TEST EQUIPMENT AND METHODS

Leach columns were constructed from 2- or 4-ft lengths of 3-in-inside-diameter (ID) polyvinyl chloride (PVC) pipe equipped with cemented couplings and bushings in which perforated Nalgene plates had been installed. A 9-cm G6 borosilicate glass fiber filter was placed on the perforated plate before installation of the bushing.

In one study, fifteen 2-ft columns and fifteen 4-ft columns were matched into 15 sets. A single tailings sample was distributed between one 2-ft (1.75 kg) and one 4-ft (7.0 kg) column. In another series (residence-time effect), a single tailings sample was used in thirty-two 2-ft columns, each containing 1.5 kg of tailings. A series of 12 similarly constructed 1-1/2-in ID PVC columns were used to examine the effect of atmosphere on metal dissolution from two different tailings, with six columns being filled with 650 g of each waste. Leachants were introduced to the columns drop by drop from a 1-L polypropylene storage bottle through Tygon tubing fitted with a screw clamp. Volumes of leachant depended on an experimen-

tally determined tailings "pore" volume. Estimates of the pore volume were made by filling the columns with the appropriate weight of dry tailings and enough leachant to saturate the column plus an additional 100 cm^3 or so. The difference between the leachant and leachate volumes led to the defined pore volume.

ANALYTICAL EQUIPMENT

The metal analyses reported in this investigation were carried out with the aid of a Perkin-Elmer Plasma II ICP spectrometer. Anion analysis was conducted with a Dionex 4000i ion chromatograph equipped with an AS4A separation column.

DISCUSSION AND RESULTS

In a previous study (Doepker 1988), there was evidence from column leach experiments that leachate metal concentrations depended on leachate residence time (i.e., the total time a pore volume of leachate remained in contact with column waste material). For any experimental protocol that utilizes 1 pore volume per leaching, the residence time is simply the time between leachings. Later work (Doepker 1989), showed that this residence-time effect occurred in unsaturated tailings while saturated tailings exhibited no increase in metal concentrations with increased residence time. These studies involved tailings that produced near-neutral to slightly basic leachates. Table 2 shows a part of a similar study using acidic copper mine A tailings. Leachate metal concentrations from saturated columns remained constant over a 54-day period while unsaturated tailings produced the enhanced metal dissolution characteristics of oxygen-sensitive sulfides containing waste.

The role of atmospheric oxygen was further examined with two different Montana copper mine tailings, mine A and C. Three columns of each tailings were placed into a chamber in which a nitrogen atmosphere was maintained while the leachant was allowed to be saturated with oxygen. Three other columns of each tailings were exposed to the normal laboratory atmosphere and used as a comparison. It should be mentioned that although the chamber atmosphere was maintained at or below 2% oxygen, leachate metal concentrations between the chamber and the laboratory atmosphere were identical within experimental variability. It can also be shown that a 28-day dry cycle produced very little enhanced metal dissolution in either the chamber or the laboratory atmosphere. Two explanations can be considered. First, sufficient oxygen to maintain a slow degradation of the tailings was present in the undegassed leachants or, second, microorganisms still active at these low oxygen pressures were responsible for the dissolution. If one considers the limited amount of enhanced metal dissolution from the unsaturated tailings observed in this test series, it is conceivable that the leachate metal concentrations were simply solubility-controlled dissolution from sulfate-rich tailings.

Six 3-in OD, 28-in-long PVC columns were "pushed" into the tailings in a main tailings impoundment of the gold-copper mine. Two locations were examined, using three columns each. The columns were then removed from the tailings and the top 3 to 4 in of tailings within the columns were discarded to facilitate the addition of leachants. These six columns were subsequently leached with synthetic rain and later with 0.01 M Na_2HPO_4, pH = 9.30 (table not included). The results indicate that, although the two sites produced different leachate metal concentrations, both showed the same overall behavior with each subsequent leaching, as well as very little dry cycle effects. It should be added that the addition of phosphate to

these samples over 7 pore volumes (seven leachings) had very little effect on the metal dissolution or on a 29-day dry cycle. An exception to this statement was an eight- to tenfold increase in leachate sulfate after the columns appeared to become saturated with phosphate. It appears that phosphate simply replaced sulfate as the principal anion. Other studies conducted with gold-copper mine tailings, and copper mine tailings A and C showed similar results with the addition of phosphate leachant.

In an on-going study, tailings from seven copper mines have been leached over the past 2 years with synthetic rain and subjected to two dry cycles of 2 months each. Tailings have shown a very systematic decrease in metal dissolution with time, but some have demonstrated enhanced activity during unsaturation (dry cycle). Space precludes the inclusion of all of these data, but a number of observations will be made here. The basic setup included two columns for each sample, each containing 7.0 kg or 1.75 kg of waste. Approximately 1 pore volume of leachant was added to the shorter column while the same volume (equivalent to 1/4-pore volume) was added to the longer columns. Leachings of these columns were carried out approximately once a month with synthetic rain.

Gold-Copper Mine Tailings

The initial leachate metal concentrations from both long and short columns were similar although the sample depths were 40 and 10 in. Concentrations plotted on a per-pore volume base for the two columns were the same within experimental variance. Table 3 presents an abbreviated set of element analyses of leachates from the shorter of these columns. This sample shows considerable metal enhancement when the columns were allowed to partially dry (table 3).

Copper Mine A Tailings

As reported above, the leachate metal concentrations from both the long and short columns were initially the same and remained so on a per-pore volume basis. Therefore, table 4 reports selective data for the short column only. High sulfate and high metal concentrations were observed to diminish slowly with each pore leaching, but little enhanced metal dissolution occurred from unsaturated conditions.

Copper Mine B Tailings

Table 5 reports the results of the short-column studies of samples taken at two depths within the same tailings impoundment. Although there appears to be some variation of metal and sulfate concentrations in the column leachates, the overall characteristics of metal dissolution remain the same for both sample depths. Sulfate production is somewhat affected by unsaturation as well as a drop in leachate pH. It should be emphasized that these effects are nearly lost when columns depths of 39 in are used.

Copper Mine C Tailings

These tailings were found to be the most diverse of the all the samples in the variety of distinct mineral phases present. The results from the short column (table 6) show that tailings produce high metal dissolution and that are extremely sensitive to a dry cycle. It should be pointed out that a second sample reported to come from the same source as mine C tailings was used in the chamber study reported upon earlier in this paper. No such dramatic dry-cycle effect was observed.

Table 3.--Leachate concentrations from gold-copper mine tailings
(1.75 kg waste; 10 in column depth; 375 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L						
				Al	Ca	Cu	Fe	Mg	Mn	Zn
Start...	3.36	7.45	6,900	>800	498	1,150	46.7	102	0.22	487
3.......	2.93	12.13	14,800	>800	449	1,150	247	267	11.3	>400
3.......	2.96	5.52	5,500	466	467	569	52.2	96.2	3.64	314
4.......	2.93	2.88	NA	154	128	NA	NA	33.6	5.5	>400
3.......	2.95	1.88	924	41.6	232	33.8	32.2	10.4	1.05	30.2
4.......	3.07	1.38	531	22.9	81.6	24.4	10.5	8.98	.93	20.4
4.......	2.73	1.48	495	36.6	44.6	22.8	17.6	7.91	.39	23.5
4.......	2.61	1.68	705	69	60.4	49.6	22.6	15.8	.95	32.2
8[1]......	2.34	8.8	8,640	1,410	138	828	205	120	6.94	438
4.......	2.53	3.29	2,190	264	47.7	151	141	60	3.11	114
4.......	2.51	2.65	1,690	193	52.9	69.2	165	45.4	2.61	79.4
4.......	2.63	2.3	1,200	129	41.3	36	102	38.3	1.17	41.7
4.......	2.63	1.66	736	73.1	36.4	21.1	66.6	31.3	1.44	26.8
4.......	2.66	1.25	465	34.1	21.9	10.5	27.2	20.1	1.17	15.4
4.......	2.69	1.08	444	31.7	29.5	9.14	37.3	19.2	1.07	13.1
4.......	2.69	1.07	356	24.3	25.1	6.65	30.8	17.5	.84	11
4.......	2.82	1.01	350	21.2	28.1	6.12	26.9	18.3	1.01	10
8[1]......	2.65	4.61	5,290	631	111	109	99.6	95.5	3.44	84.7
4.......	2.53	2.23	1,040	98.9	25.7	26.2	145	37.1	1.28	29.4
4.......	2.62	1.84	915	51.9	15.3	11.9	32.9	27.3	.99	20.4
2.......	2.55	1.45	619	42.1	18.6	10.2	69.7	37.7	1.19	20.5
2.......	2.72	1.17	368	20.1	14.8	6.54	30.7	20.5	.62	9.93
3.......	2.8	1.02	301	13.8	13.6	4.33	30.9	16.9	.49	6.62

NA No analysis.

[1] Dry cycle, columns opened to atmosphere.

Table 4.--Leachate concentrations from copper mine A tailings
(1.75 kg waste; 9.5 in column depth; 400 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L						
				Al	Ca	Cu	Fe	Mg	Mn	Zn
Start.......	3.31	NA	7,140	NA	446	NA	>400	1,510	>160	490
3...........	3.18	7.3	6,890	113	455	341	569	479	61.2	113
3...........	3.07	4.72	4,360	46.5	490	166	13	351	20.5	54.5
4...........	3.04	4.31	3,900	39.3	541	134	5.87	325	20.6	55
3...........	2.94	3.66	2,690	26.4	486	80.1	4.51	194	9.93	27.4
4...........	3.02	3.45	1,400	10.5	301	30.3	2.22	83	2.99	12.4
4...........	2.7	3.37	1,910	18.6	446	31.6	5.36	114	3.19	19.1
4...........	2.77	3.41	2,320	21.4	642	44.5	8.61	130	5.64	28.1
8[1]	2.38	4.46	2,710	148	517	203	29.2	127	6.21	41.4
4...........	2.52	3.45	1,940	55.5	660	79.8	16.7	66.6	3.02	31.9
4...........	2.65	3.01	1,860	51.4	703	67.8	16.8	60.4	3.2	43.9
4...........	2.72	2.99	2,010	35.9	639	41.6	9.19	23.1	1.42	19.8
4...........	2.7	2.96	1,840	29.5	685	29.8	9.45	13.8	.88	11.7
4...........	2.61	2.91	2,020	23.7	574	20.8	7.41	8.93	.62	11
4...........	2.68	2.74	2,650	33.1	772	27.7	8.13	9.77	.82	12.4
4...........	2.71	2.72	2,120	23.3	564	20.2	5.63	9.05	.59	11.8
4...........	2.87	2.72	1,680	21.7	700	18.5	3.11	3.35	.52	9.19
8[1]	2.54	3.56	2,270	57.8	568	34.7	17.6	18.6	1.42	21
4...........	2.61	2.91	1,460	36.4	523	25.3	8.47	11.3	.92	16.4
4...........	2.66	2.44	1,420	26.9	404	24.5	7.13	8.77	.87	13.8
2...........	2.67	2.33	1,310	25.4	429	29.6	7.99	13.2	1.19	18.5
2...........	2.78	2.03	1,060	13	320	18.8	4.83	7.59	.69	11.3
3...........	2.8	2.15	1,120	15.7	378	23.7	4.44	13.7	.8	15

NA No analysis.

[1] Dry cycle, columns open to atmosphere.

Table 5.--Leachate concentrations from copper mine B tailings
(1.75 kg waste; 9.5 in column depth; 450 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L						
				Al	B	Ca	K	Mg	Mo	Na
SAMPLING DEPTH, 0-6 in										
Start.......	7.05	>20	852	0.09	0.27	158	55	68.6	2.52	2,190
3...........	7.83	6.42	1,830	.04	.21	545	129	110	2.89	490
3...........	7.85	3.26	1,983	<.01	.33	419	78	82.2	2.07	104
4...........	8.15	1.545	675	<.01	.28	282	45	19.3	NA	43.6
3...........	8.7	.415	93.6	.03	.31	68.9	23.4	3.89	1.38	38.5
4...........	8.26	.391	63.6	<.01	.27	28.9	15.3	2.45	NA	20.9
4...........	7.87	.393	78	<.01	.32	40.7	18	2.48	.54	12.9
4...........	8.1	.54	145	.02	.4	78	24.7	5.53	.63	8.64
8[1]	7.48	1.59	912	.04	.64	409	58.3	26.7	2.83	14.6
4...........	7.86	.961	336	.03	.36	173	41.3	12.2	1.21	11.7
4...........	7.95	.721	293	.07	.44	89.6	21.5	10.4	3.55	4.48
4...........	7.84	.627	175	.3	.65	99.1	27.5	8.83	6.38	5.48
4...........	7.99	.641	176	.21	.43	97.2	29.4	8.53	8.34	6.46
4...........	7.85	.638	220	.29	.54	106	28.7	10.4	11.7	7.1
4...........	7.88	.644	169	.93	.58	89.7	22.8	8.22	9.94	5.53
4...........	8.02	.616	175	<.01	.42	86.4	23.2	10.6	11.3	5.07
4...........	8.14	.684	219	<.01	.41	106	25.6	6.92	7.51	6.24
8[1]	7.63	.952	376	.1	.53	133	23.3	10.9	7.45	5.58
4...........	7.78	.802	305	<.01	.68	157	27.8	9.65	5.37	7.1
4...........	8.04	.827	333	.07	.55	148	27.4	9.46	4.02	7.4
2...........	7.85	.677	214	<.01	.4	89.6	18	6.6	2.06	4.13
2...........	7.92	.694	173	.06	.38	101	19.4	5.32	1.34	4.47
3...........	7.91	.662	192	.24	.68	100	19	8.07	1.55	4.53
SAMPLING DEPTH, 6-12 in										
Start.......	7.72	5.21	2,910	0.24	0.51	502	88.8	150	2.13	650
3...........	8.19	2.15	816	8.19	.14	183	31.8	32.7	1.31	179
3...........	8.24	.483	94.5	<.01	.42	46.9	24.6	8.64	1.32	24
4...........	8.64	.603	185	<.01	.46	94.5	41.4	18.1	NA	18.6
3...........	8.7	.547	128	.01	.31	94.8	33.9	13.2	.53	9.01
4...........	8.4	.651	203	<.01	.37	86.2	31.8	15.4	NA	5.82
4...........	8.1	.691	178	.01	.39	87.5	31.2	15.6	.29	3.57
4...........	8.01	.735	222	<.01	.56	109	38.9	20.5	.34	4.88
8[1]	7.15	1.71	864	.01	.95	135	52.6	51.8	.69	9.45
4...........	7.9	.867	309	.01	.51	131	34	19.1	.57	10.8
4...........	8.01	.715	299	.04	.58	84.2	21.9	18.9	1.81	4.96
4...........	7.9	.677	191	.26	.69	96	25.8	16.7	3.47	5.32
4...........	8.06	.667	198	.18	.49	98.7	29.8	15.7	5.03	6.21
4...........	7.85	.67	209	.12	.57	98.3	28.4	16.7	6.16	5.69
4...........	7.93	.648	119	.79	.53	83	22.6	8.92	3.96	5.09
4...........	8.04	.64	182	<.01	.45	98.6	23.7	15	5.54	4.34
4...........	8.04	.68	204	<.01	.51	97.8	22.9	12.3	5.2	4.75
8[1]	7.86	1.02	411	.05	.68	138	23.4	18.7	5.39	5.05
4...........	7.8	.953	385	<.01	.68	171	28.3	19.9	3.87	5.57
4...........	8.05	.877	202	.03	.57	136	22.5	15.5	2.57	4.88
2...........	7.96	.816	283	<.01	.44	103	17.7	13.2	1.58	3.37
2...........	7.98	.642	148	.05	.46	92.6	19.2	9.17	1.25	3.85
3...........	7.89	.537	129	.21	.68	76.4	15.2	9.15	.92	3.49

NA No analysis.

[1] Dry cycle, columns opened to atmosphere.

Table 6.--Leachate concentrations from copper mine C tailings
(1.75 kg waste; 8.5 in column depth; 250 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L							
				Al	As	Ca	Cd	Cu	Fe	Mn	Zn
Start...	2.98	1.95	6,750	326	4.66	>160	49.6	>3,200	2,140	>170	>400
3.......	2.76	10.04	7,710	52.5	13.4	117	.02	>3,200	506	47.8	>400
3.......	2.74	4.47	4,590	14.9	8.1	40.1	2.25	1,270	218	15.8	>400
4.......	2.26	3.81	2,060	13.8	.1	45.2	.51	140	126	9.96	250
3.......	2.48	2.71	1,610	5.91	4.3	7.37	.39	190	373	7.83	176
4.......	2.36	3.6	1,800	8.99	NA	13.3	.08	197	344	3.99	80.3
4.......	2.15	3.44	1,450	12.3	6	11.2	.77	128	361	1.52	53.7
4.......	2.13	3.6	2,200	30.5	11.9	23.2	1.29	148	615	3.36	72.6
8[1]......	1.53	19.32	11,800	199	305	25.5	54.5	1,400	3,560	5.44	497
4.......	1.82	11.02	6,870	79.5	165	17.7	8.16	667	2,080	5.02	379
4.......	1.79	7.07	3,840	33.5	39.4	8.25	2.1	279	1,269	3.01	257
4.......	2.21	4.13	2,310	13.8	24	1.9	.73	118	719	1.21	126
4.......	2.23	2.7	1,350	7.2	6.4	4.5	.36	70.8	420	1.37	100
4.......	2.19	2.37	929	4.6	3	1.86	.25	32.5	247	1.07	71.5
4.......	2.3	2.19	925	4.93	3.1	4.19	.24	25.9	278	1.16	79.8
4.......	2.3	2.18	804	3.72	2.2	1.94	.27	21.7	206	.91	83.9
4.......	2.43	2.01	780	4.4	2.4	.667	.3	26	189	.82	106
8[1]......	2.02	10.26	6,980	63.5	44.8	6.68	1.92	292	1,100	2.31	476
4.......	2.15	2.35	999	6.56	1.7	<.01	.38	43.6	231	.47	116
4.......	2.51	1.9	830	2.62	1.4	<.01	.24	27.9	156	.4	75.8
2.......	2.33	1.62	494	1.3	1.6	<.01	.13	12.6	87.3	.28	42
2.......	2.62	1.311	266	.75	0	<.01	.09	8.65	43.8	.17	29.2
3.......	2.65	1.26	258	1.02	2	.13	.1	8.04	44.6	.2	27.7

NA No analysis.

[1] Dry cycle, columns opened to atmosphere.

Table 7.--Leachate concentrations from copper mine D tailings
(1.75 kg waste; 9 in column depth; 0-6 in sampling depth; 325 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L							
				B	Ca	Cu	K	Mg	Mn	Mo	Na
Start...	8.25	0.377	157	0.02	79.1	0.33	41.9	5.5	0.03	0.75	2.1
3.......	8.18	.987	348	.13	138	.22	52	10	.08	1.15	3.5
3.......	8.28	.443	99.3	.11	55	.12	32.8	4.11	.01	.87	2.56
4.......	8.19	.381	57.6	.12	44.1	.1	27.2	3.15	<.01	NA	2.37
3.......	8.11	.324	54	.21	45.4	.13	24.4	6.03	.03	.56	2.4
4.......	8.08	.334	68.7	.16	48.7	0	23.9	3.48	<.01	NA	2.1
4.......	7.84	.32	61.5	.24	41.5	.12	18.1	2.96	.02	.64	2.17
4.......	8.05	.35	59.7	.26	48.8	.15	16.8	3.09	.01	.99	2.72
8[1]......	7.8	.531	178	.3	82.3	.08	20.1	5.28	.03	6.9	4.2
4.......	7.74	.37	143	.53	63.7	.24	13.8	4.34	<.01	8.56	4.71
4.......	7.8	.436	158	.55	96.5	.29	18.5	7.02	.01	15.9	7.51
4.......	7.49	.436	104	.46	67.2	.24	11.6	3.96	<.01	10.4	5.43
4.......	7.89	.412	92.2	.19	138	.35	41.4	11.5	.1	20.2	3.77
4.......	7.63	.395	100	.48	55	.52	8.1	3.68	<.01	11.5	6.04
4.......	7.85	.411	107	.7	63.6	.44	7	4.14	.04	13.7	7.52
4.......	7.79	.413	106	.48	61.6	.39	6	3.38	.02	15.2	5.87
4.......	7.61	.443	120	.55	77.5	.54	6.3	1.35	.02	19.2	7.01
8[1]......	7.13	.637	240	.65	127	.35	7.3	4.21	.03	34	7.29
4.......	7.24	.476	150	.56	78.1	.35	4.5	1.59	.04	20.4	7.26
4.......	7.24	.41	135	.44	60.9	.25	3.4	.63	.02	18.3	5.27
2.......	7.23	.303	69.3	.46	45.3	.27	3.3	.2	.04	12.9	4.05
2.......	7.15	.282	63.9	.39	35.1	.17	1.9	<.01	.03	9.55	3.67
3.......	7.44	.268	64.8	.3	40	.52	1.7	2.01	.03	10.3	4.04

NA No analysis.

[1] Dry cycle, columns opened to atmosphere.

Copper Mine D Tailings

Although these tailings are mineralogically similar to copper mine A and B tailings, the metal concentrations from dissolution seem to mirror the low leachate sulfate and the sample's total sulfur as opposed to general mineralogy. The overall behavior of the metal dissolution follows the general rules of the other samples except that dissolution enhancement from unsaturated tailings is very small. Table 7 reports a portion of the collected data from this tailings sample.

Copper Mine E Tailings

The major difference among the Arizona tailings may be seen in the mineral form of the copper present in the tailings. These tailings (table 8) produce extremely high amounts of sulfate along with high amounts of copper-containing leachates, while relatively abundant chalcopyrite appears in the tailings. These tailings did not produce the expected enhanced dissolution associated with unsaturation, but this may be due to the fact that these tailings contain a considerable amount of fines, which prevents a great deal of evaporation, and produce columns that require many weeks to elute 1 pore volume of leachate. Table 8 reflects the differences and similarities in composition often observed in sampling two locations within the same tailings impoundment.

Copper Mine F Tailings

Pyrite and chalcopyrite are present and yet the copper concentration (short columns) in leachates remain equal to or below 0.1 mg/L; iron is below 1.0 mg/L. High sulfate production (table 9) was observed in both the long and short columns and yet metal dissolution appears low. Leachate pH remains high for both copper mine D and F tailings, while high metal concentrations were observed for the low pH leachate of copper mine E tailings.

SUMMARY AND CONCLUSIONS

Although this study was limited to seven copper mine tailings, the results reported here and in other on-going studies seem to indicate certain common behaviors. High sulfate production is more commonly associated with high metal concentrations and is indicative of tailings that are susceptible to atmospheric oxidation. If tailings produce acidic leachates, dry cycles often produce relatively small changes (less than one order of magnitude) in metal concentrations, while tailings that normally produce basic leachates may demonstrate enhanced metal dissolution of one to two orders of magnitude. Leachate concentrations from packed columns of 6 to 12 in produce observable wet/dry cycle effects while longer columns reveal little observable metal enhancement from unsaturated conditions. The high leachate sulfate, and high metal concentrations initially observed in air-dried tailings, followed by rapidly falling concentrations with subsequent leachings, appear to reflect oxidative reactivity and/or highly oxidized tailings samples. Acid tailings (tailings that produce acid leachates) appear to be sulfate driven, that is, sulfate is present in the sample from mobile metal sulfate complexes. It is suspected that the use of biocides and other treatment methods may have little effect on metal dissolution until this "excess" sulfate is eluted.

It must be pointed out that column test protocols appear to have the ability to distinguish potentially reactive tailings from benign tailings,

Table 8.--Leachate concentrations from copper mine E tailings
(1.75 kg waste; 9 in column depth; 0-6 in sampling depth; 400 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L Al	B	Ca	Cd	Co	Cu	Fe	Mg	Mn	Na	Ni	Zn
HOLE 1															
Start.....	3.02	>20	25,900	1,400	0.2	179	0.43	77.8	1,290	77.7	312	>800	798	NA	123
3.........	3.09	8.46	5,850	302	.29	403	.05	13	248	7.57	410	193	168	NA	18.2
10........	3.18	4.13	3,090	84.1	.36	480	.38	2.92	70.2	5.09	213	49.2	86.6	NA	6.15
8.........	2.95	3.33	2,710	66.8	.4	536	.01	1.23	47.1	3.81	92.1	15.3	48.6	.57	4.01
12[1]	2.84	1.58	2,140	88.6	.38	658	<.01	.82	24.6	2.93	51	10.8	46	.69	1.98
8.........	2.91	1.51	2,230	73.9	.29	584	.01	.41	27.5	3.67	24	3.43	22.1	.29	1.99
8.........	2.92	2.93	1,690	67.9	.27	631	.01	.27	17.5	2.54	15.8	2.02	18.7	.15	.82
4.........	2.98	2.8	1,840	33.9	.19	351	<.01	.02	7.77	5	6.85	.94	7.2	.04	.88
4.........	2.93	2.65	2,120	48.2	.23	790	<.01	.04	7.02	5.81	6.7	.87	15	.08	.06
4.........	2.92	2.72	1,910	39.9	.17	654	<.01	<.02	4.41	3.46	4.11	.57	12.7	.03	.58
4.........	3.22	2.56	1,840	27	.16	643	.01	<.02	1.36	.58	0	.08	10.2	.01	<.01
8[1]	3.36	2.34	1,330	16.6	.14	558	<.01	.04	2.15	1.77	.39	.4	10.9	.02	.79
HOLE 2															
Start.....	2.77	<20	21,100	84.6	.38	134	1.1	54.5	2,450	4.8	242	>780	2,500	NA	326
3.........	2.82	7.09	5,430	33.3	2.27	432	.16	14.2	784	1.27	307	83.3	654	NA	234
10........	4.1	4.11	2,740	12.6	.99	268	.91	2.64	186	.94	124	47.8	25.3	NA	18.3
8.........	3.81	3.44	2,890	16	1.28	518	.04	2.35	250	.39	93.2	53.3	11.6	2.69	18.7
12[1]	3.2	8.98	2,650	59.6	1.24	558	.03	2.43	354	14	78	34.1	9.6	2.24	17.6
8.........	3.02	3.41	2,910	39.7	.85	343	.03	1.68	247	3.46	56	22	2.98	1.71	23.8
8.........	3.03	2.89	1,900	42.7	1.09	641	<.01	.8	130	.7	33.4	7.69	7.92	.88	4.9
4.........	3.25	2.72	1,960	30.8	.88	438	<.01	.43	90.1	1.98	21.6	5.85	4.96	.52	3.44
4.........	3.25	2.58	2,120	36.7	1.2	702	.01	.7	100	.85	32.8	7.18	6.99	.89	4.17
4.........	3.37	2.49	2,080	8.04	.36	624	.01	.22	40	.78	6.99	2	1.7	.24	1.57
4.........	3.51	2.44	1,530	6.76	.29	544	.01	.32	31.1	0	1.79	.95	1.85	.12	1.02
8[1]	3.14	2.78	1,960	25.8	.34	611	<.01	.57	81.4	1.35	9.61	1.79	2.86	.28	2.5

NA No analysis.

[1] Dry cycle, columns open to atmostphere.

Table 9.--Leachate concentrations from copper mine F tailings
(0-6 in, hole 1 sampling depth; 350 cm^3 synthetic rain leachant)

Time between leachings, weeks	pH	mmho	SO_4, mg/L	Element, mg/L						
				B	Ca	K	Mg	Mn	Mo	Na
1.75 KG WASTE; 8.5 IN COLUMN DEPTH										
Start...	8.28	5.56	2,740	0.39	417	80.6	16.6	0.27	1.55	892
3.......	8.02	3.89	1,840	.55	487	93.6	24.7	.37	1.92	258
3.......	8.01	3.76	2,340	.54	534	87.5	23	.25	.82	390
3.......	8.04	2.9	2,110	.58	653	87	25.5	.29	.24	96.8
3.......	7.93	2.65	1,800	.5	724	93.3	39	.62	.35	96.5
4.......	7.98	2.53	1,410	.4	483	46.2	17.8	.26	.09	12.7
4.......	7.76	2.51	1,580	.52	467	40.7	16.2	.31	.09	10.6
4.......	7.88	3.72	1,420	.66	533	36.4	19	.38	.12	4.04
8[1]	7.73	2.61	1,760	.81	667	49.4	18.4	.45	.42	19.6
4.......	7.8	2.52	2,100	1.35	633	40.9	21.5	.43	1.33	20.1
4.......	7.77	2.45	2,820	1.36	686	28.2	23.1	.35	1.05	8.71
4.......	7.71	2.43	1,560	1.13	713	29.6	12.6	.39	.27	11.1
4.......	7.95	2.39	2,140	1.18	516	21.1	10.1	.55	.29	8.92
4.......	7.77	2.42	1,440	.77	458	17.3	5.3	.41	.19	10.6
4.......	7.89	2.38	1,140	1.06	361	11.9	3.48	.29	.14	8.81
4.......	7.94	2.42	1,450	1.08	531	12.8	6.19	.68	.26	6.78
4.......	7.75	2.46	1,330	.92	564	12.3	<.005	.24	.16	9.59
8[1]	7.65	2.46	1,360	.92	702	11.4	1.04	.34	.37	12.4
4.......	7.8	2.34	1,300	.88	642	9.2	<.005	.37	.57	10.9
4.......	7.85	2.25	1,400	1.02	612	7.9	<.005	.23	.57	10.6
2.......	7.68	1.81	970	.95	441	5.5	<.005	.15	.52	8.8
2.......	7.7	1.44	767	.79	341	4.1	<.005	.06	.36	10.8
3.......	7.76	1.06	492	.55	238	3.7	.53	.04	.29	9.63
7 KG WASTE; 34 IN COLUMN DEPTH										
Start...	8.27	7.03	3,630	0.54	448	88.1	5.4	0.24	5	1,340
3.......	8.19	6.3	342	.7	367	94.5	20.5	.22	2.39	1,070
3.......	8.06	5.14	2,970	.33	481	98.4	23.2	.18	.99	809
4.......	7.98	4.97	1,860	.33	738	128	35.3	.31	.81	492
3.......	7.91	4.11	1,640	.48	742	89.8	37.7	.55	.81	116
4.......	8	3.11	1,800	.19	531	84.7	32.6	.43	.81	108
4.......	7.84	3.35	2,100	.23	504	83.5	30.9	.6	.18	244
4.......	7.88	3.72	1,650	.24	488	70.7	27.6	.49	.17	108
8[1]	7.8	3.44	1,960	.36	535	93.2	29.8	.46	.31	283
4.......	7.74	2.99	2,530	.43	533	80.2	34.7	.4	.48	126
4.......	7.66	2.77	3,090	.59	658	92.5	58.5	.61	.7	77.8
4.......	7.67	2.73	1,540	.36	632	85	31.8	.06	.36	56.7
4.......	7.86	2.67	1,740	.43	501	76.3	35.3	.2	.38	37.1
4.......	7.65	2.71	1,560	.43	474	63.1	28.1	.15	.37	27.7
4.......	7.82	2.69	1,530	.77	512	77	28.2	.19	.59	29.3
4.......	7.86	2.72	1,630	.74	570	74.4	45.1	.28	.88	24.8
4.......	7.67	2.77	1,820	.62	626	79.2	29.9	.21	.98	29.1
8[1]	7.59	2.75	1,820	.61	622	86.4	32.4	.17	2.91	29.4
4.......	7.7	2.58	1,550	.71	651	91.2	29.7	.23	3.19	23.8
4.......	7.75	2.57	1,540	.66	533	66	25.4	.22	3.21	21.2
2.......	7.71	2.64	1,560	.75	631	66.4	23	.41	3.44	19.4
2.......	7.74	2.79	1,640	.71	621	70	19.9	.45	3.04	19.7
3.......	7.8	2.74	1,530	.62	624	57.2	20.1	.45	3.14	16.5

[1] Dry cycle, columns opened to atmosphere

but do not necessarily reflect what may occur in the natural setting of the tailings themselves.

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Stabilization of Acidic Mine Tailings in a Pristine Alpine Environment

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ABSTRACT

The McLaren Tailings site is located in Park County just east of Cooke City, Montana. Approximately 150,000 cubic yards of waste (tailings) from a gold and silver milling operation occupy roughly 10 acres in the valley floor of Soda Butte Creek. The tailings are confined by an earth dam and capped with 1.5 to 3.0 feet of soil. Several environmental problems are posed by the site including: 1) leachate seeping from the left and right abutments of the dam degrades the water quality of Soda Butte Creek, 2) surface runoff from exposed wastes at the old mill site degrades the water quality of Soda Butte Creek, and 3) the tailings dam is susceptible to failure (either structurally or due to breaching during flood events) in which event a significant load of acidic, metal-laden mine tailings would be released to Soda Butte Creek. Adding to the sensitivity of the situation is the location of Yellowstone National Park a mere 5 miles downstream from the site. Efforts to stabilize the site and reduce the potential for further degradation to Soda Butte Creek were undertaken by the Bureau of Reclamation in support of a co-operative effort between the Environmental Protection Agency, the National Park Service, the Forest Service, and the Fish and Wildlife Service.

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LOCATION

The McLaren Tailings site is located in Park County just east of the community of Cooke City, Montana. It encompasses approximately 10 acres in the Soda Butte Creek valley floor and occupies both Gallatin National Forest and private properties. The site is situated approximately 5 miles upstream on Soda Butte Creek from the northeast entrance to Yellowstone National Park.

BACKGROUND

Ore from the McLaren Mine (part of the New World Mining District) was processed primarily for gold and silver extraction using a cyanide leaching process at the site from the 1870's until 1967 (MDSL, 1986). Approximately 150,000 cubic yards of waste from the milling operation was deposited on the valley floor of Soda Butte Creek, which originally meandered through the area currently overlain by the mill tailings. The Bear Creek Mining company leveled and capped the tailings with approximately 1.5 to 3.0 feet of soil during the late 1960's. Soda Butte Creek was re-routed around the north edge of the tailings during this same time. This "reclamation" effort was brought about primarily as a result of pressure from the National Park Service and the Montana Department of Fish, Wildlife and Parks to reduce impacts of runoff and seepage from the tailings to Soda Butte Creek (Duff, 1972).

The site has been investigated by several parties since the 1960's. The most recent of these was conducted by the Environmental Protection Agency (EPA) in 1987 and 1988. A preliminary endangerment assessment conducted by EPA during those investigations concluded:

1. The tailings do not currently pose a significant threat to human health.

2. The major impact of the tailings is environmental. The continuing release of acidic, heavy metal contaminated water from the tailings severely impacts the ecosystem of Soda Butte Creek.

3. Runoff from the tailings and seepage from the dam abutments are violating Montana water quality standards for Soda Butte Creek and compromising water quality within Yellowstone National park.

4. Failure of the tailings dam would result in a substantial release of contaminated material into Soda Butte Creek. The environmental consequences of such a release would be significant and extend downstream into YNP.

PROGRAM OBJECTIVE

In the fall of 1988, the United States Bureau of Reclamation (USBR) was requested by EPA to develop and evaluate a range of alternatives which would significantly mitigate or eliminate the degradation potential of Soda Butte Creek presented by the tailings and the mill site. The agencies involved stipulated that alternatives must meet the following criteria:

1. keep annual operation and maintenance costs to a minimum,

2. be compatible with the environmental sensitivity of the area, and

3. be compatible with potential reprocessing of the tailings at an undetermined date in the future.

SITE CHARACTERIZATION

Soils

The tailings were reportedly leveled and covered with approximately 1.5 to 3.0 feet of alluvial material by the Bear Creek Mining Company in the late 1960's. The majority of this cover material was probably borrowed from the sloped areas along the southern perimeter of the site. Field inspection revealed that the soil cover generally ranges from 2 to 5 feet in depth and can be classified as a sandy loam in texture according to the United States Department of Agriculture (USDA) textural classification system.

The soil cover performs several functions. First, it prevents direct contact by surface traffic with the underlying tailings. Second, it provides a relatively contaminant-free medium for establishment of vegetation. Third, it tends to reduce surface runoff from the site. Fourth, it enhances infiltration of rainfall and snowmelt to the tailings by virtue of the cover's relatively course texture.

A re-analysis of data obtained during an earlier Montana Bureau of Mines and Geology (MBMG) investigation suggests that an infiltration rate of approximately 0.75 inches/hour may be representative for the site. Although the surface materials will allow rapid infiltration of precipitation, infiltration is slowed considerably once the wetting front reaches the finer textured tailings below the soil cover.

Limited sampling and analysis for selected trace elements was conducted to determine concentrations present in the soil cover. These data are compared with results from samples obtained outside the site boundary in the following table:

Table 1: Total Trace Element Concentrations for Soil Samples

			mg/kg (ppm)				
Sample ID	Location	Sample Depth	As	Cu	Fe	Pb	Zn
B-38	cover	0-20"	15	38	10000	33	40
B-39	cover	0-35"	19	25	9000	33	40
B-40	cover	0-29"	19	31	13000	36	40
B-44	background	1-8"	30	82	23000	67	110
B-45	background	1-8"	34	57	24000	69	190
B-46	background	1-8"	30	82	23000	104	130

Based on these data, it appears that inorganic contaminants are not migrating upward from the tailings into the soil cover.

Tailings

The tailings are usually grey in color and a fine, sandy loam in texture (based on the USDA classification method). The profile is typically gleyed with a few oxidation zones present. At most boring sites, iron pyrites are readily visible in auger cuttings. Investigations have reported that the tailings range from 1 to 35 feet in thickness (MDNRC, 1977).

Tailings samples have been analyzed for a wide variety of constituents during the course of several investigations. The trace elements arsenic, copper, iron, lead, and zinc continually occurred at significant concentrations, as indicated in the following table:

Table 2: Total Trace Element Concentrations for Tailings Samples

		mg/kg (ppm)				
Sample ID	Sample Depth	As	Cu	Fe	Pb	Zn
MCTW-3	near surface	58	12600	198000	672	222
MCTW-5	near surface	38	3630	196000	88	90
MCTW-6	near surface	35	841	137000	123	46
B-38	36-72"	97	1882	204000	84	40
B-39	36-72"	79	3220	227000	98	90
B-40	36-72"	81	5350	235000	96	110

To help determine the solubility in water (and therefore mobility) of these trace elements, some samples were also analyzed using a 1:10 water-extract procedure. The results of that analyses (see Table 3) indicate that copper and iron are both susceptible to transport via water movement through the tailings.

Table 3: Water Soluble (1:10 extract) Trace Element Concentrations for Tailings Samples

		mg/kg (ppm)				
Sample ID	Sample Depth	As	Cu	Fe	Pb	Zn
B-38	36-72"	0.2	36.1	155.3	1.6	1.6
B-39	36-72"	0.1	408.0	32.1	1.8	2.8
B-40	36-72"	0.1	342.0	10.8	1.1	3.5

Surface Water

Soda Butte Creek was diverted around the north edge of the tailings pile in the late 1960's by Bear Creek Mining as part of a site stabilization effort. The creek, a tributary to the Lamar River, originally traversed the valley floor currently occupied by the tailings. Miller Creek joins Soda Butte Creek along the north edge of the site.

Stream discharges in excess of 100 cfs can occur during periods of peak flow, usually in June or July. However, the average flow between the months of November and April is less than 0.5 cfs (MDNRC, 1977). Studies conducted by MBMG indicate that groundwater base flow discharges to Soda Butte Creek provide the predominant stream flows (during low-flow periods). In addition, in-stream monitoring of Soda Butte Creek indicates that the stream loses water over a substantial portion of the stream reach near the northeast corner of the tailings site. It is believed that this loss to the groundwater system occurs predominantly via the original creek channels.

Flood studies conducted by the U. S. Geological Survey (USGS) using channel geometry techniques produced 50- and 100-year design flood flows of 1040 and 1430 cfs respectively for Soda Butte Creek above the Miller Creek confluence. Below the confluence with Miller Creek, the 50- and 100-year flood discharges are 1200 and 1620 cfs respectively, according to the same study.

These flood flows were routed through the Soda Butte Creek channel in the vicinity of the tailings site using WSPRO, a step-backwater computer program developed by USGS. According to this study, the computed 10-year discharge (430 cfs) would leave the stream banks along the northeast edge of the tailings. In addition, approximately 700 cfs of the 100-year flow would discharge across the tailings in this area. A flood discharge of this magnitude would likely wash out the tailings dam.

EPA's Region VIII Emergency Response Branch conducted limited sampling of surface water during their field investigations in 1987. These data (see Table 4) indicate that the trace elements aluminum, copper, iron, and manganese all occur in higher concentrations at stations below the tailings dam than at stations above the dam. Of these constituents, only iron was present at concentrations toxic to aquatic life. These data likely do not reflect the potential influence of surface runoff from the mill/ore site. Contaminant loading from this area would probably be short-term in nature and related to local runoff events for which data are not readily available.

Table 4: Selected Trace Element Concentrations for Soda Butte Creek Samples

Sample ID	Sample Station	pH	As	Cu	Fe	Mn	Pb	Zn
				*ug/l (ppb)				
MHH-001	above tailings	7.3	10u	9u	140	4u	5u	9u
MHH-002	above confluence with Miller Creek	7.1	10u	9u	100	4u	5u	9u
MHH-003	below confluence with Miller Creek	7.2	10u	9u	250	9	5u	9u
MHH-004	above tailings dam seeps	7.1	10u	11	890	25	5u	9u
MHH-005	below tailings dam seeps	6.7	10u	9u	1020	25	5u	9u
MHH-006	below MHH-005	6.7	10u	9u	2850	70	5u	9u

* "u" following a numerical value indicates the constituent was undetected at that limit.

Groundwater

MBMG installed approximately 37 observation wells between 1973 and 1975 in an effort to determine groundwater flow conditions in the vicinity of the tailings. Streamflow studies of Soda Butte Creek were also conducted by MBMG during this period. This study concluded that the annual water outflow from the area (both groundwater and surface water) is approximately twice the annual streamflow (as measured just below the tailings dam). A review of the 1975 data indicates that approximately 24 percent of the total surface inflow is lost to groundwater recharge in the immediate vicinity of the tailings. Roughly 85 percent of this loss occurs where Soda Butte Creek is re-routed around the northeast corner of the tailings.

Groundwater levels within the tailings usually decline from a high in June or July to a low in February or March. These water levels typically fluctuate approximately 10- to 12-feet between maximum and minimum readings. Flow lines drawn on groundwater contour maps developed from the MBMG study tend to converge along the old Soda Butte Creek alignment. These observations are in general agreement with conclusions reached during the MBMG investigations.

Active seeps are visible at both the left and right abutments of the tailings dam during most times of the year. Leachate from these seeps discharges directly to Soda Butte Creek a short distance downstream from the dam. The precipitation of iron compounds in the immediate vicinity of the seeps is highly visible and often apparent a good distance downstream from the source.

Trace element analysis was conducted on water samples obtained from: 1) monitoring wells completed in the tailings, 2) monitoring wells completed in the alluvium below the tailings, and 3) the active seeps. Selected data from these analysis are displayed in the following table:

Table 5: Selected Trace Element Concentrations for Groundwater & Seep Samples

Sample ID	Sample Station	pH	As	*ug/l (ppb) Cu	Fe	Mn	Pb	Zn
MHH-028	tailings well	7.0	10u	30	3250	162	22	54
MHH-029	tailings well	6.1	10u	9u	94300	4640	28	234
MHH-030	tailings well	7.2	10u	9u	43u	217	5u	9u
MHH-032	tailings well	5.3	10u	60	302000	26700	5u	2280
MHH-033	tailings well	6.2	10u	9u	1000	3560	5u	9u
MHH-008	left abutment	6.2	10u	9u	10500	1160	5u	97
MHH-009	right abutment	5.0	10u	81	117000	2940	5u	152
MHH-010	center of dam	5.0	10u	437	51800	2010	5u	167

* "u" following a numerical value indicates the constituent was undetected at that limit.

Structural Integrity

A stability analysis of the tailings dam was conducted in 1983 (Maddox, 1983). The study concluded that four of five failure surfaces analyzed had a safety factor of less than one. These findings prompted the investigator to conclude that failure of the dam is imminent.

USBR reviewed the Maddox report and applied that data to SSTAB2 (Chugh, 1971), a modified version of the Spencer Method for stability analysis (Spencer, 1973). Based on this analysis, the dam was found to exhibit marginal static stability, (i.e., a safety factor of approximately 1 was determined). In addition to the marginal static stability conditions, liquefaction of the dam is also considered to be a potential threat because the dam is located in an area which has a significant probability for seismic activity.

Biological Impacts

Conditions in Soda Butte Creek have improved significantly since the early years of mill operation. This conclusion is based on a review of available documentation and laboratory data. However, the creek environment still suffers from iron contamination resulting from the periodic release of acidic, metal laden leachate into the stream.

Should failure of the tailings dam occur, the physical action of such a release would likely scour the stream channel for some distance downstream from the dam. Deposition of metal laden sediments within the stream channel would also occur, smothering fish spawning grounds and decreasing available substrate for invertebrate production. The release of toxic compounds from these sediments would be dependent on several factors.

SITE STABILIZATION

Hazard Characterization

Based on investigation data and site observation, the hazards presented by the site can be categorized as follows:

1. runoff and seepage from the Old Mill and Ore Storage areas

2. flooding of Soda Butte Creek and the subsequent dam failure potential)

3. tailings dam failure (hydrogeologic and seismic failure potentials)

4. seepage from the tailings and tailings dam

Alternative Development

Alternatives were developed to address each of these hazard categories (USBR, 1989). In most cases, corrective actions suggested by previous investigators (ERT, 1988; MDNRC, 1977; MDSL, 1986) were carried through the evaluation process. As discussed earlier, corrective action alternatives also had to meet the following criteria:

1. keep annual operation and maintenance costs to a minimum,

2. be compatible with the environmental sensitivity of the area, and

3. be compatible with potential reprocessing of the tailings at an undetermined date in the future.

Alternative Evaluation

The alternatives were then evaluated according to their **effectiveness**, **implementability**, and **cost**. Because the site does not present an immediate threat to human health (the primary impacts are environmental), an administrative decision was made to only address the dam safety concerns at the site. Accordingly, the following corrective actions were selected for implementation:

1. An emergency dike would be constructed along the northeast edge of the tailings to prevent flood flows in Soda Butte Creek from flowing across the tailings.

2. A subsurface drain would be constructed along the southern perimeter of the site to intercept groundwater recharge from the slope to the south.

3. Construction of a cut-off wall just downstream of the emergency dike to reduce groundwater recharge from Soda Butte Creek would be further considered.

4. A stability berm would be constructed along the downstream toe of the existing tailings dam.

All of these corrective actions address the dam stability problem, either physically or hydraulically. In addition, the subsurface drain and the cut-off wall both help to reduce recharge to the tailings and therefore have the potential to reduce seepage of leachate from the site.

SUMMARY

The emergency dike was constructed in the spring of 1989 and geologic investigations to verify subsurface conditions were conducted in the fall of 1989. Design of the previously mentioned features is currently ongoing, and an award for construction is scheduled for June 1990. Construction of the stability berm, the subsurface drain, and the cut-off wall are scheduled for fall of 1990. Upon completion of these features, the potential for failure of the tailings dam and seepage of acidic leachate will be substantially reduced.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

TITLE

THE USE OF ATTENUATION CAPACITY STUDIES TO EVALUATE THE SUITABILITY OF SOILS FOR THE DISPOSAL OF STORMWATERS FROM HEAP LEACH FACILITIES

K. J. Lang[1]

ABSTRACT

A study was conducted to evaluate the suitability of native soils at a gold mine site for the irrigation and disposal of stormwaters originating from a proposed heap leach facility. A batch experiment was utilized to quantify the metal attenuation capacity of soils occupying the proposed disposal area as a function of soil depth and stormwater metal concentration.

Samples of soil, representing A, B, and C horizon material, were equilibrated with five synthetic stormwater solutions which ranged in total dissolved solids (TDS) from 728 ppm to 12,200 ppm and which contained ions in proportions observed in pregnant solutions of ore leachate. Retention of ions by the soil was determined by analyzing the concentration of ions remaining in solution after a 72 hour equilibration period. The ions of primary concern in the study included As^{2+}, Cd^{2+}, Cr^{3+}, Pb^{2+}, Mn^{2+}, Mo^{6+}, Ni^{2+}, Zn^{2+} and Ag^{+}.

Attenuation of metals by soil was greater for subsurface materials and generally increased with decreasing metal concentration. Different trends were observed for Mo^{6+}, Cr^{3+}, and Ni^{2+} including the negative attenuation of Mn^{2+}. Although the experiment was not designed to identify specific attenuation mechanisms, absorption and precipitation/co-precipitation were the primary mechanisms attributed to the retention of metal ions by the soil. Based on the overall results of this study, the metals were attenuated in the order; Cu > As > Zn > Cr > Cd > Ni > Ag > Mo >>> Mn. It was concluded that the upper 60 inches of soil at the proposed disposal site had well in excess the total attenuation capacity needed to immobilize metals irrigated as stormwater from the proposed heap Leach facility.

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INTRODUCTION

Irrigation is a viable method which can be used to discharge and dispose of storm waters from retention or surge ponds at heap leach facilities. A study was designed and conducted to evaluate the suitability of soils at Western Energy Company's proposed Chartam gold mine, near Winston, Montana, for storm water land disposal as part of the permit acquisition requirements. To accomplish this, a batch experiment was utilized to quantify the metal attenuation capacity of native soils occupying the proposed disposal area. Pre-irrigation baseline soil chemical data were also collected as needed to assess the impacts of stormwater disposal through post irrigation soil monitoring.

MATERIALS AND METHODS

Samples were collected with a Gidding's hydraulic soil auger from the Radersburg series along two separate transects within the proposed stormwater disposal area as illustrated in Figure 1. Five to six locations along each transect were sampled in three depth increments (0-6, 6-12, and 12-60 inches) intended to represent A, B, and C horizon materials. The samples from each depth increment were composited for an entire transect to provide a total of six samples.

These samples were used for both pre-irrigation baseline and attenuation capacity evaluations. All laboratory work was conducted by Northern Engineering and Testing, Inc. of Billings, Montana according to procedures approved by the Montana Department of State Lands. The results of characterization and pre-irrigation soil chemical baseline analysis are provided in Tables 1 and 2, respectively.

The procedure used to determine attenuation capacity was modified from work conducted by Hassett and Groenewold (1986). In our study, the composition of a pregnant solution obtained during test leaching at the proposed Chartam Mine was used to design attenuating solutions intended to simulate discharge water quality. A base solution with a TDS concentration of 12,200 ppm was initially prepared containing the predominant ions in the proportions observed in the pregnant solution, except that an adjustment was made with $CaCl_2$ to account for CN neutralization. From the base solution, four additional solutions were made from dilutions with the weakest solution having a TDS concentration of 728 ppm. The object was to represent a range of possible discharge water qualities from typical to worse case and, at the same time, produce meaningful attenuation capacity data for the soils in question. The composition of the attenuating solutions is reported in Table 3.

In our procedure, ten grams of soil were equilibrated with 100 ml of each solution for 72 hours. After centrifuging the mixture, the supernatant was filtered and analyzed to determine the amount of a particular ion remaining in solution. The ions of primary concern in this study included As^{2+}, Cd^{2+}, Cr^{3+}, Pb^{2+}, Mn^{2+}, Mo^{6+}, Ni^{2+}, Zn^{2+}, and Ag^{+} because of their environmental significance or because they were dominant in the pregnant solution.

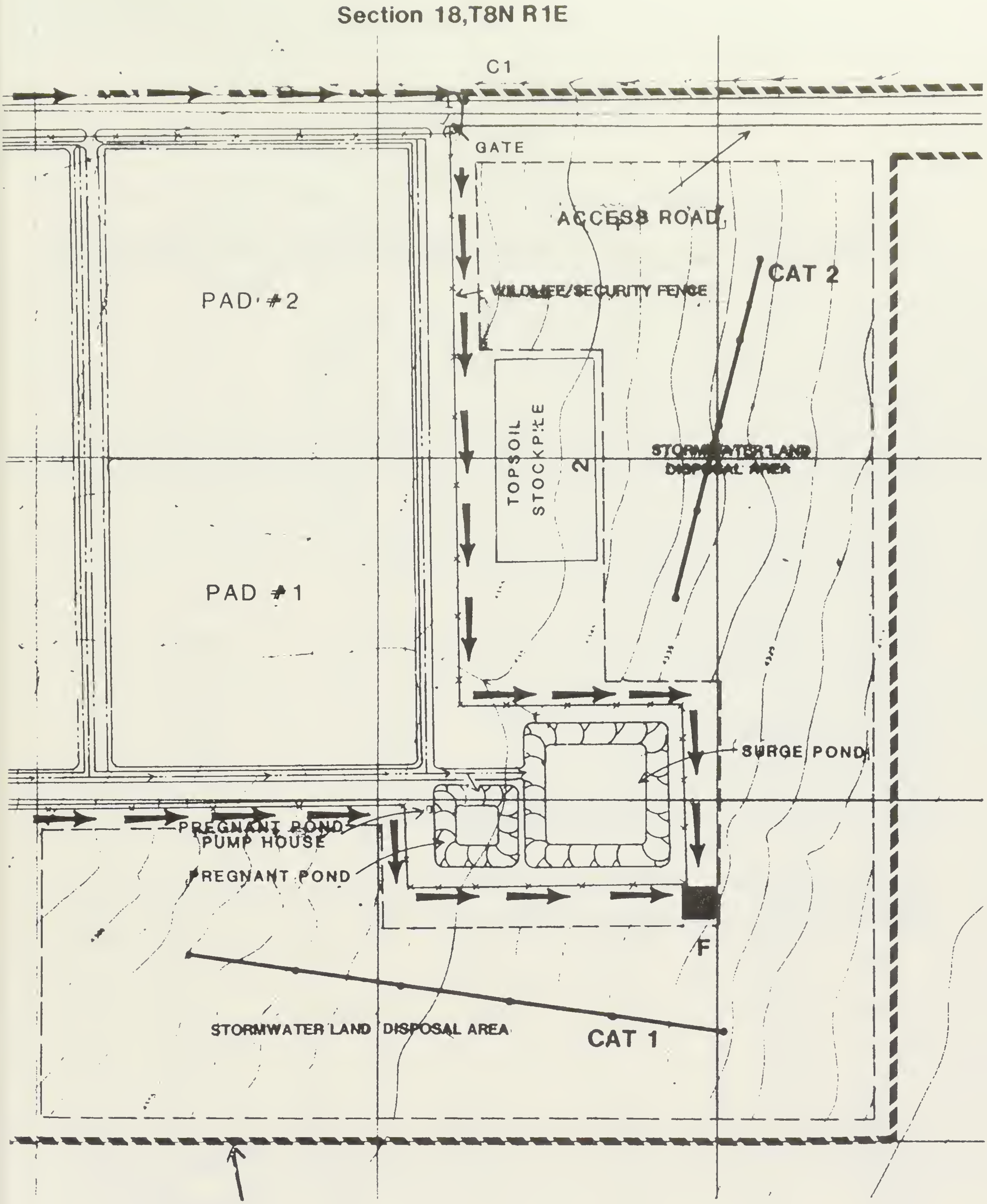

FIGURE 1

Stormwater Land Disposal Area Soil Baseline and Attenuation Sample Locations

Table 1
Land Disposal Area
Soil Characterization Data

Site	Depth	pH	EC	Satn	Ca	Mg	Na	SAR	$CaCO_3$	OM	CEC	Sand	Silt	Clay
			mmhos/cm	%	--------meq/1--------				%	%	meq/100g	-----------%---------		
CAT1	0-6	4.7	0.29	30.6	1.20	0.08	1.17	1.51	2.06	1.5	13	58	32	10
	6-12	6.3	0.53	29.2	5.19	1.15	0.70	0.39	2.69	1.5	14	63	25	12
	12-60	6.7	0.46	34.9	4.19	0.74	0.91	0.58	5.54	1.8	18	52	34	14
CAT2	0-6	5.6	0.33	28.3	1.95	0.41	0.57	0.52	2.05	1.7	13	62	30	8
	6-12	6.7	0.49	34.5	4.04	1.15	0.83	0.56	4.73	1.1	16	61	24	15
	12-60	1.8	0.65	31.7	6.29	1.64	1.00	0.50	8.37	1.1	13	67	21	12

Table 2
Land Disposal Area Soil
Pre-irrigation Baseline Chemical Data
(ppm)

Site	Depth	Analysis	As	Cd	Cr	Cu	Mn	Mo	Ni	Ag	Zn	CN
CAT1	0-6	Total	23.4	9.93	56.8	24.8	639	17.7	14.2		85.1	0.30
		Extractable	1.5	0.04	1.2	0.4	51	1.0	<0.4	<0.4	2.2	
	6-12	Total	9.88	8.02	43.2	18.5	410	15.4	21.6		67.9	0.37
		Extractable	0.54	0.26	1.0	<0.4	57.6	<1.0	<0.4	<0.4	0.6	
	12-60	Total	10.2	13.1	46.5	20.3	534	14.5	29.0		72.6	0.28
		Extractable	0.28	0.34	4.6	0.6	153	<1.0	<0.4	<0.4	2.6	
CAT2	0-6	Total	39.0	12.8	61.3	33.4	752	13.9	27.9		136	0.30
		Extractable	1.8	0.1	1.4	0.4	75	<1.0	0.6	<0.4	3.8	
	6-12	Total	28.8	11.8	53.2	31.0	670	11.1	28.8		115	0.43
		Extractable	0.54	0.44	1.2	0.4	61	<1.0	<0.4	<0.4	1.2	
	12-60	Total	24.1	10.05	57.0	32.9	877	11.0	28.5		116	0.25
		Extractable	0.66	<0.1	1.4	0.4	65	<1.0	<0.4	<0.4	1.0	

Table 3
Concentrations of Ions in
Synthetic Irrigation Water
(ppm)

Al^{3+}	0.36	0.08	0.10	0.04	0.03
As^{3+}	7.20	2.70	1.80	0.95	0.44
Cd^{2+}	8.96	3.10	1.68	0.87	0.41
Ca^{2+}	1,910	583	371	199	93
Cr^{3+}	1.30	0.48	0.19	0.17	0.095
Co^{2+}	0.05	0.05	0.017	0.007	0.014
Cu^{2+}	113	43.9	22	12.8	7.9
Fe^{2+}	1.56	0.62	0.36	0.20	0.10
Pb^{2+}	0.08	0.03	0.06	0.06	0.042
Mn^{2+}	0.38	0.14	0.07	0.04	0.02
Mg^{2+}	<5	<5	<5	<5	<5
Hg^{2+}	0.088	0.036	0.025	0.0046	0.0032
Mo	6.48	2.44	1.68	0.78	0.34
Ni^{2+}	0.90	0.32	0.18	0.095	0.056
K^{+}	284	137	79	32	15
Ag^{+}	0.89	0.52	0.48	0.32	0.26
Na^{+}	1,730	543	331	173	80
Zh^{2+}	103	36.2	21.0	10.9	4.67
CN^{-}	0.33				0.01
$C1^{-}$	4,110	1,440	812	411	200
SO_4^{2-}	907	253	178	64	39
$NO_3^{-} + NO_2^{-}$	449	145	92.9	48	23.5
TDS	12,200	4,250	2,700	1,410	728

Attenuation was calculated using the equation:

$$\% \text{ Retention} = \frac{C_i - Ceq}{C_i} \times 100 \qquad (1)$$

where C_i is the initial concentration in ppm, and Ceq is the equilibrium concentration in ppm. Attenuation capacity was calculated for the metals of concern for each depth increment and for each attenuating solution and then averaged over both transects. Plots of C_i vs. % Retention for individual metals and each soil increment are presented in Figures 2 through 10.

RESULTS AND DISCUSSION

Hassett and Groenewold (1986) provided a good summary of attenuation mechanisms. Probably the most dominant mechanism responsible for metal attenuation in our study was adsorption or ion exchange followed by precipitation and co-precipitation. Because of the large number of ions included in the attenuating solutions, and the complex interactions between these ions and the soil solution, it would be impossible and certainly beyond the scope of this study to identify specific mechanisms. However, the information presented in Figures 2 through 10 does quantify attenuation capacity and does provide some indication of the mechanisms involved.

With the exception of Mo, which is more strongly attenuated by surface organic matter, metal attenuation capacity generally increased with soil depth. This was probably due to a higher clay content and cation exchange capacity and the possible formation of less soluble carbonate compounds. While metal attenuation generally increased with decreasing concentration, Cr exhibited an opposite trend and Ni attenuation appeared to peak at some intermediate concentration. Probably one of the most interesting phenomena observed in this study was the negative attenuation of Mn. Apparently, Mn was readily stripped from exchange sites in response to preferential adsorption by other metals. Although Pb was included in the study, initial and equilibrium concentrations were too near detection limits to provide meaningful data. However, Pb would be expected to behave much like Cd, Cu, or Zn. Based on the overall results of this study, the metals were attenuated in the following order.

$$Cu > As > Zn > Cr > Cd > Ni > Ag > Mo >>> Mn$$

CONCLUSIONS

According to the results of this study, the Radersburg series is highly suitable for stormwater land disposal. The upper 60 inches of this soil had well in excess the total attenuation capacity needed to intercept and immobilize metals irrigated as proposed. In addition, attenuating mechanisms such as dilution and dispersion, which are a part of the natural leaching/transport process, would provide an additional margin of safety.

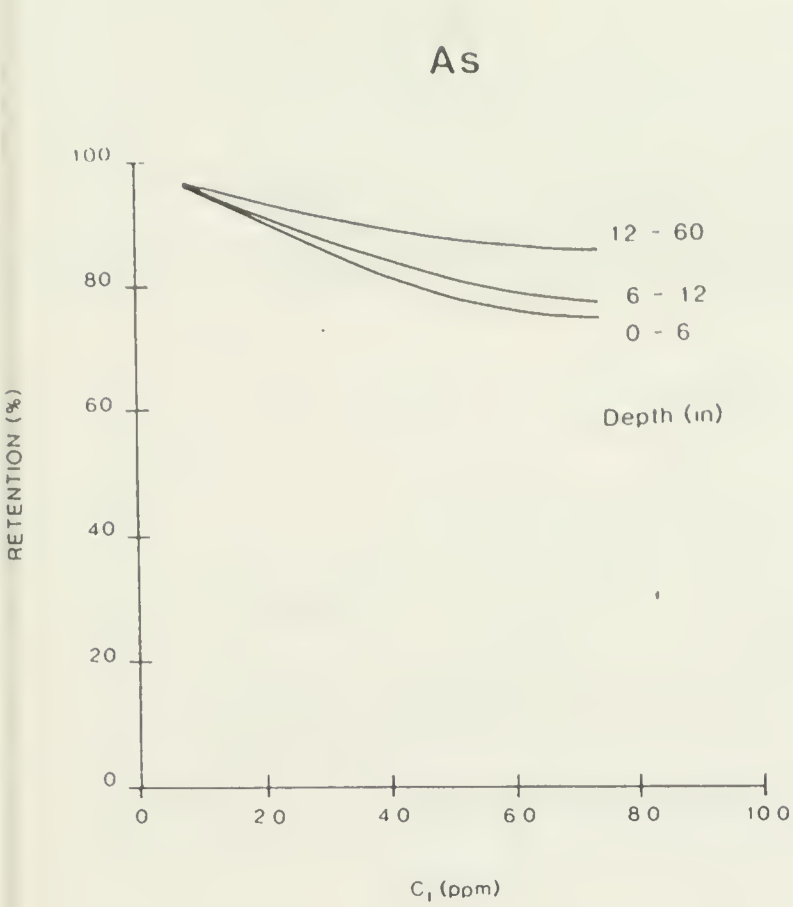

Figure 2

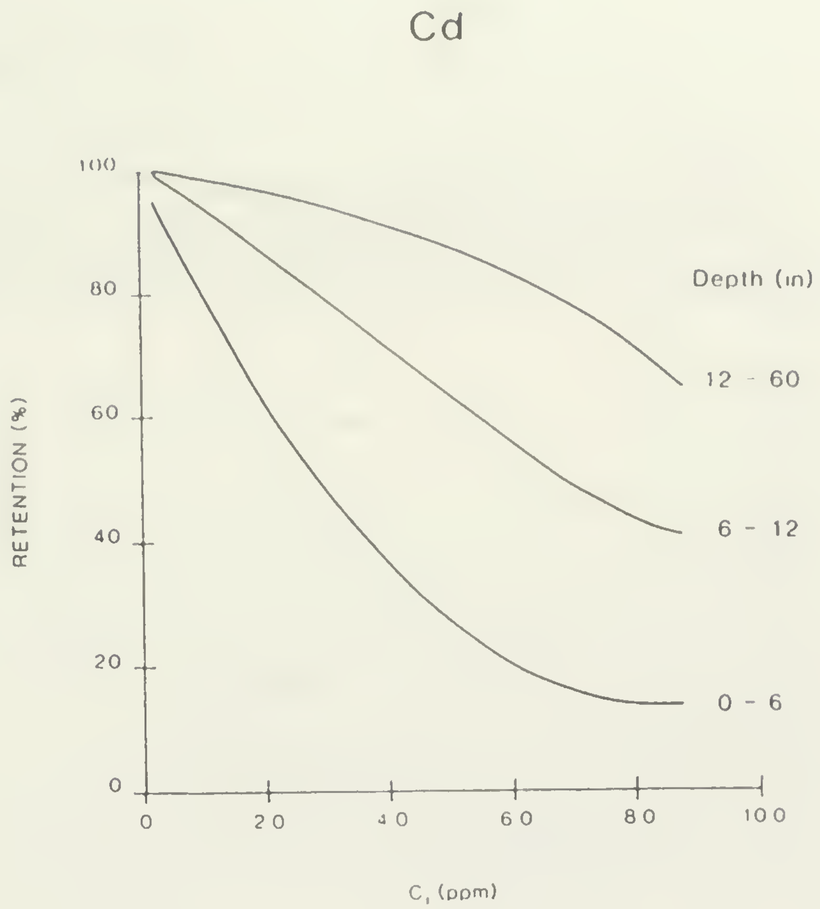

Figure 3

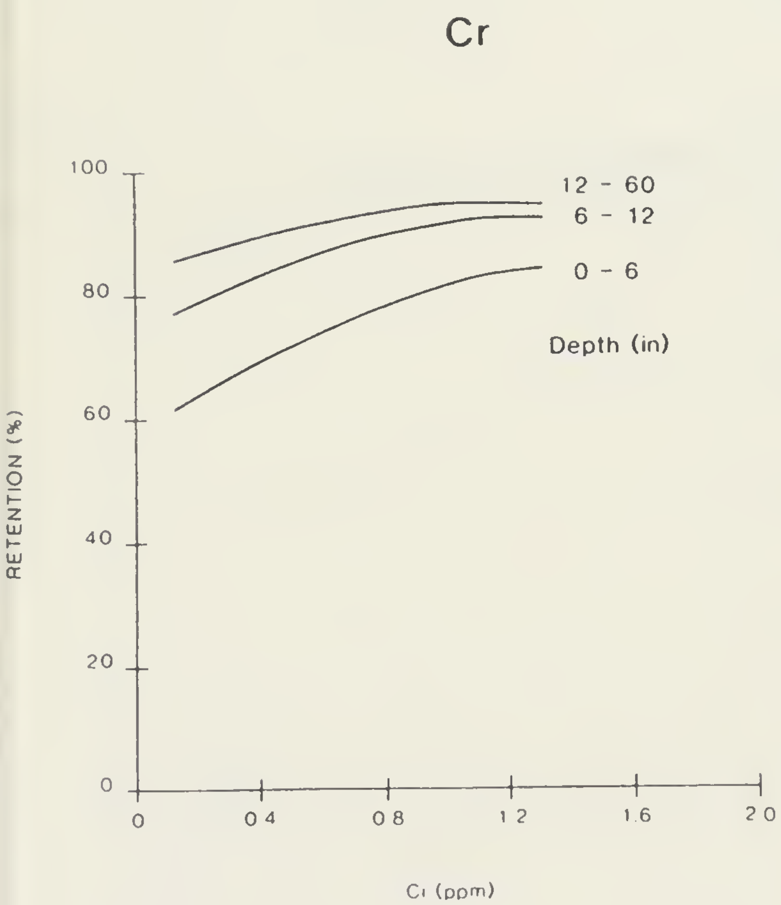

Figure 4

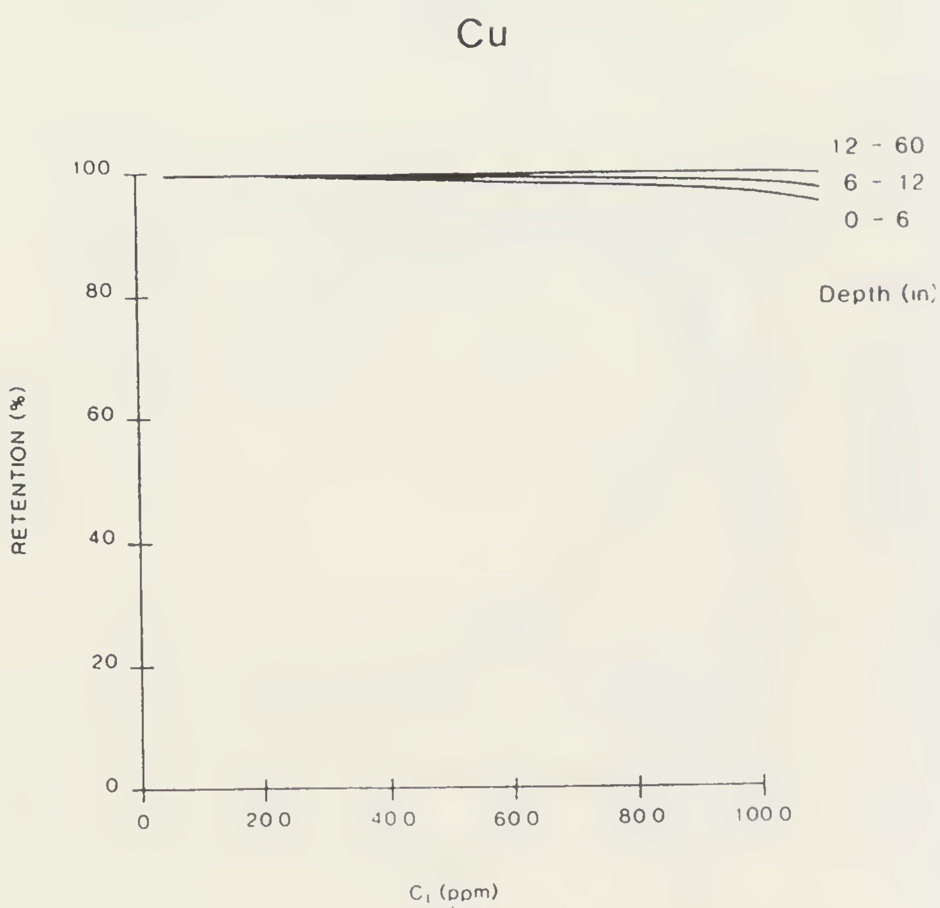

Figure 5

Mn

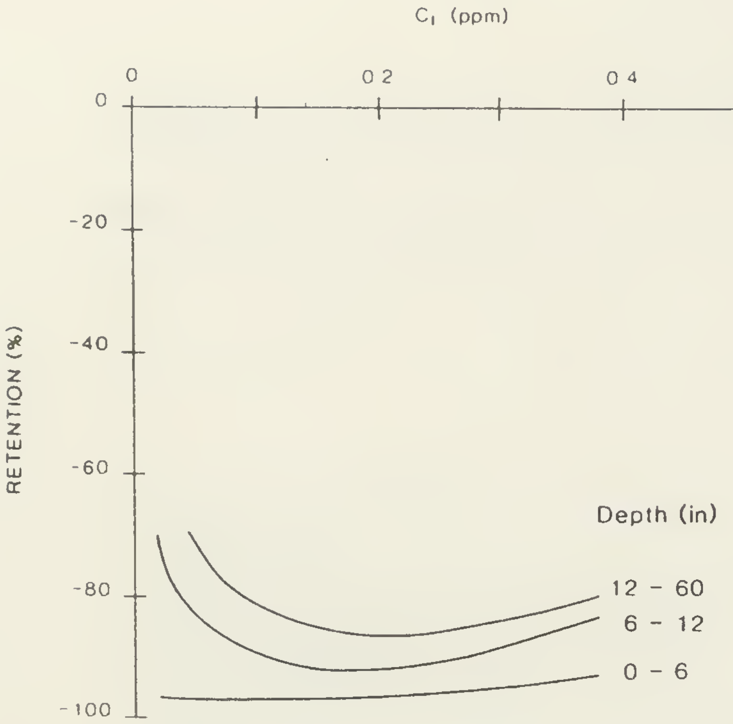

Figure 6

Mo

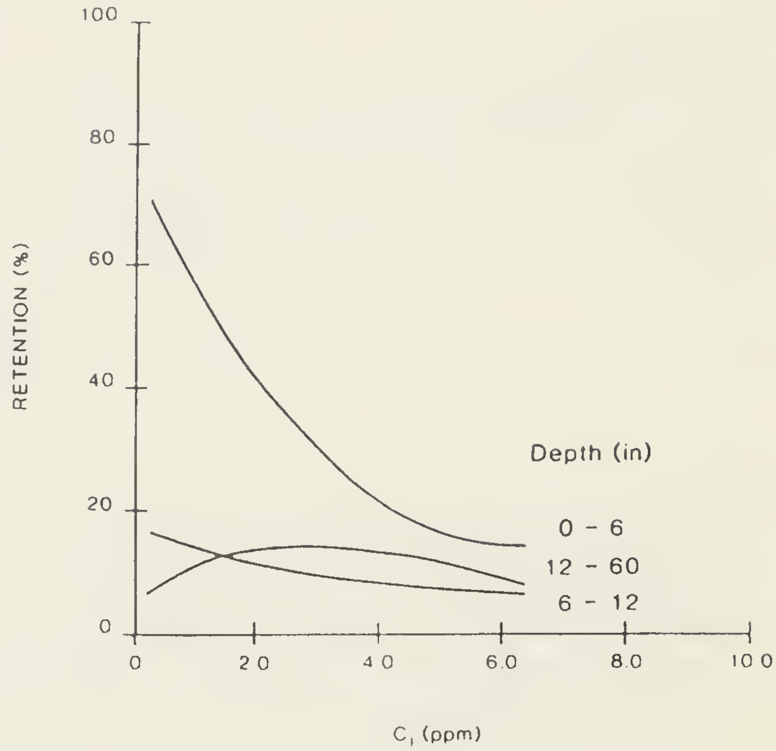

Figure 7

Ni

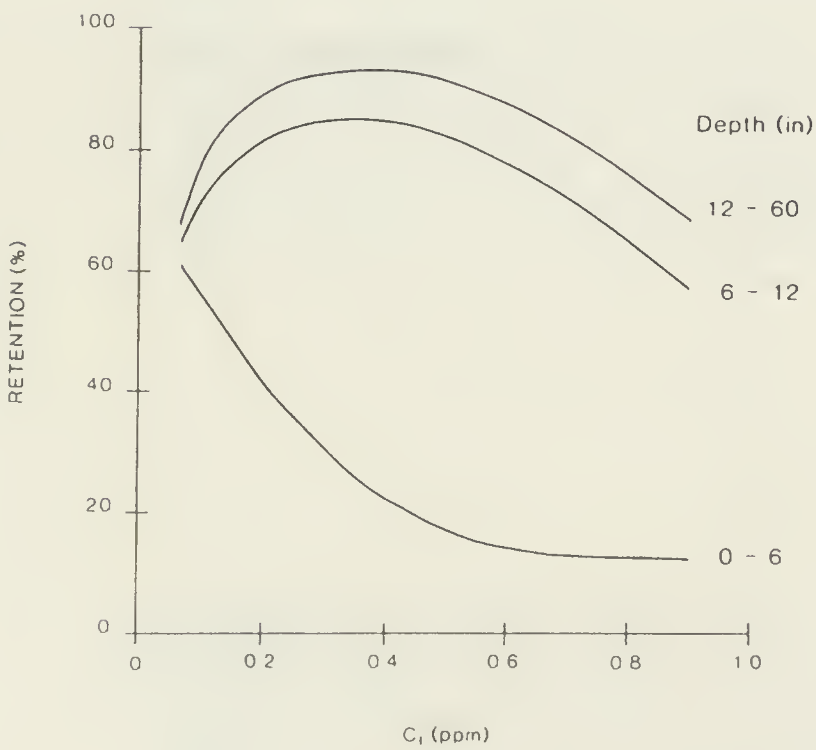

Figure 8

Zn

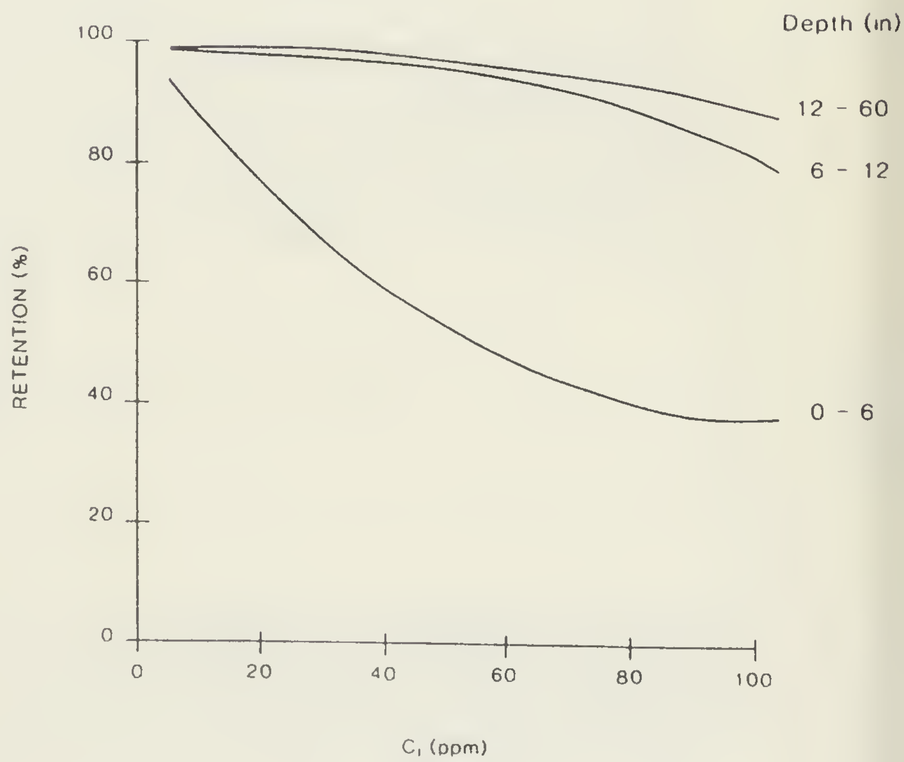

Figure 9

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Planning, Rehabilitation, and Treatment of Disturbed Lands
Billings Symposium, 1990

Land Application of Cyanide-Containing Mining Process Solutions[1]

by
William M. Schafer[2] and Thomas Hudson [2]

ABSTRACT

An increase in the use of heap leaching for extraction of precious metals has brought about a need for cost-effective, environmentally reliable treatment and disposal methods for cyanide process solutions. While cyanide can be destroyed rather completely through a number of chemical processes, treated process solutions often contain a significant concentration of heavy metals. Land application to soil systems has been used for treatment of metal-enriched solutions. Soils have the ability to strongly adsorb many metals, hence, improving the quality of water discharged from the mine-site. The ability of soil systems to attenuate metals in treated process solutions is the subject of this investigation.

1 - *We would like to acknowledge Pegasus Beal Mountain Mine for funding this research*
2 - *Schafer and Associates, Bozeman, MT 59715*

INTRODUCTION

Heap Leach Gold Mining

A number of mines in the western U.S. utilize a "heap leach" method for recovery of disseminated gold from oxidized ore material. The low cost inherent in heap-leaching allows mining of low grade ores. To extract gold, a solution of cyanide-containing solution is applied by sprinkler or subsurface irrigation to the surface of a pile of permeable ore. The circulation of process solution through the ore is maintained by using coarse ore material or by agglomerating fine ore materials. Gold-bearing "pregnant" solution is collected along the lined base of the heap leach pad and drains into a pond for subsequent gold recovery and regeneration of cyanide leach solution. The processed "barren" solution is re-used on the heap.

1The heap leach system is exposed to water gains and losses through precipitation and evaporation. Many of the earliest heap leach operations were located in Nevada where water loss was substantial, creating a need for "make-up" water. In Montana, water surpluses may develop during certain seasons of operation. Hence, a need for disposal of process solution exists.

Land Application Disposal

The Pegasus Beal Mountain gold mine was permitted in 1988 for operation of a gold mine and cyanide heap leaching circuit. Permit provisions called for disposal of spent cyanide solution at the end of mine life by a combination of volatilization, photo-oxidation, peroxide oxidation, and finally land application disposal (LAD). Two areas near the mine were permitted as LAD sites. Peroxide treatment and LAD would also be used in an extraordinarily wet year to deal with excessive water inventory in the process ponds. The hydrologic probability of such a requirement is remote, however with a 100 year return internal.

Design criteria for cyanide land application disposal systems include both hydrologic and chemical considerations. The maximum expected flow rates must be determined based upon a peak storm intensity using a probability of occurrence which balances risk, cost, and expected project life. Soil intake rates must be measured for a variety of antecedent moisture conditions. Calculation of residence time of applied solution in soil may also be needed to predict cyanide volatilization, biodegradation or other kinetically slow soil chemical processes. A variety of cyanide destruction techniques are available including 1) natural volatilization and photodegradation, 2) oxidation, 3) biological treatment, and 4) recycling. Oxidation treatment of cyanide (often in conjunction with natural degradation) is the most common treatment approach. Oxidation methods include hydrogen peroxide, alkaline chlorination, and the patented INCO process among others. Finally, the soil systems capacity to adsorb heavy metals and other constituents (i.e. sodium) from applied solutions is also a concern. Frequently, metal attenuation by soils receives more regulatory scrutiny than any other aspect of land application disposal. This report describes a laboratory investigation of metal attenuation by soils in a land application disposal system.

Preliminary soil studies of the effectiveness of the proposed LAD method identified potential problems with elevated cadmium, manganese and selenium in process water leached through area soils. In the case of cadmium and manganese, peroxide treatment was able to remove these elements from the process solution effectively, but they were subsequently extracted from on-site soils. Selenium was not controlled by peroxide treatment and levels increased further after leaching through soils.

Preliminary soil column tests were conducted with a nitrogen atmosphere, under fully saturated conditions and on a single soil sample from each of two permitted LAD

areas. This protocol does not fully simulate actual soil conditions which are highly oxidizing. In addition, soil chemical properties may vary substantially with depth, thus influencing absorption of metals. Schafer and Associates was contracted to do a more detailed study of soil attenuation of metals in land-applied process solution.

STUDY OBJECTIVES

There are four principal objectives of the current study program:

- Reevaluate the proposed LAD sites in the laboratory using a column apparatus that maintains oxidizing soil conditions which may promote the attenuation of some of the metals;

- Evaluate both surface and subsurface soil samples from proposed LAD sites to determine whether metal fixation can be enhanced by treatment in a typical field soil whose chemical make-up varies with depth;

- Identify the causes for excessive levels of Mn, Cd and Fe in original column studies and recommend possible remedies should it persist in the modified laboratory procedures, and finally;

- Conduct field application tests using treated process water from the operational facility to confirm the performance of the LAD system incorporating recommended methods as required.

The first three study objectives comprise the laboratory portion of the work which are the subject of this report. The final study objective will be the subject of subsequent field tests.

METHODS

Soil Sample Preparation

Soil grab samples were collected from the three soil sampling locations. Samples were air dried and screened to remove the soil fraction larger than 2mm. Screened samples were divided using a mechanical splitter. One split was sent to Energy Laboratories for chemical analysis and the other split was retained for the soil column studies. In addition to grab samples, *in situ* samples were removed from soil pit walls at the 0 to 4 inch depth and at the 4 to 10 inch depth. The *in situ* samples were used to determine bulk density and porosity and to develop a desorption curve for water holding capacity. Column study results are only reported for a single soil location in this report.

Chemical Analysis

Soil samples were analyzed at Energy Laboratories for extractable metals. The surface soils, 0 to 4 inch depth, are slightly enriched in metal values compared to subsoil horizons. This may be due in part to the past impacts of the Anaconda smelter operation. However, the range of metal concentrations is not unusually high and it is more likely that the enrichment is due to natural processes such as the assimilation of metals by plants and concentration in the decaying matter of the organic-rich surface soils. The ability of the upper soil horizon to hold high concentrations of metals is borne out in the column tests described later.

Treatment of Barren Leach Solution

Barren leach solution was collected by Pegasus Beal Mountain operating personnel on March 13, 1989. This solution had been circulating through the leach pads since February 20th as well as for a brief period in late fall, 1988. The solution was estimated to contain approximately 1 lb/ton CN^- (500 mg/l), a typical process operating value. Actual measured values were later found to be about 65 percent of this value. The solution was treated at ambient temperature with 30 percent H_2O_2 at the rate of 1.5 lb/ton H_2O_2 in a stirred 4 liter beaker. Based on the cyanide assays obtained, this treatment rate represents a sixty percent excess according to the reaction in Equation:

$$CN^- + H_2O_2 \quad = \quad CNO^- + H_2O \qquad [1]$$

Approximately twenty minutes into the reaction both the electrochemical potential (using a bromide specific-ion electrode) and the pH of the solution began to change

rapidly. This signaled destruction of sufficient free cyanide to destabilize metal cyanide complexes. As the metals were liberated from the cyanide complex they precipitate as hydroxides or carbonates resulting in a lower solution pH. Changes in both electrochemical potential and pH were essentially complete in one hour. A green precipitate equivalent to 0.30 g/l (dry weight) was recovered but was not analyzed. The decanted solution was used for tests of the various soils for metal attenuation capacity.

In general, the destructed barren solution compared favorably with that generated by Pegasus in a metallurgical test program. Our destructed barren solution did show measurable levels of nickel and mercury contrary to the earlier test work. On the other hand, we achieved a very high degree of arsenic removal through peroxide treatment. Table 1 compares the barren leach solution, the destructed barren leach solution and the destructed leach solution used in earlier tests.

Table 1. Chemical Composition of Leach Solutions Used for LAD Studies

Component	Mine-Generated Barren Solution (mg/l)	Mine-Generated, Peroxide-Treated Barren Solution (This Study) (mg/l)	Lab-Generated, Peroxide-Treated Barren Solution (Previous Study) (mg/l)
Arsenic	0.163	<0.005	0.19
Cadmium	0.019	<0.001	<0.001
Copper	138.	2.51	3.80
Lead	<0.01	<0.01	<0.01
Mercury	0.011	0.003	<0.001
Manganese	0.09	<0.02	<0.02
Nickel	1.30	0.29	<0.03
Selenium	0.35	0.223	0.16
Zinc	0.46	<0.01	<0.01
Total Cyanide	322.	12.7	NA

Column Leach Procedures

Column tests were run in Tempe cells using an air pressure of .35 bars to move the treated barren solutions through the soil samples. These conditions more closely simulate the well-oxidized environment found in most soils than the earlier tests which were run with nitrogen overpressure. A schematic of the test apparatus is shown in Figure 1.

Column tests were run on a prepared samples from the 0 to 4 inch and 20 to 30 inch soil depth. Each test used 300 grams of dry soil mixed with sufficient peroxide-treated barren solution to obtain a saturated paste. Air pressure was applied for a period of 45 minutes to obtain extracts. At the end of an extraction cycle additional barren solution was applied to the soil sample to return the sample to its original saturated paste weight. Extracts were composited to produce samples representing approximately 0.5 pore volumes. For most samples, two or three extraction cycles were sufficient to produce this volume. Three composites representing about 1.5 pore volumes were extracted through each sample.

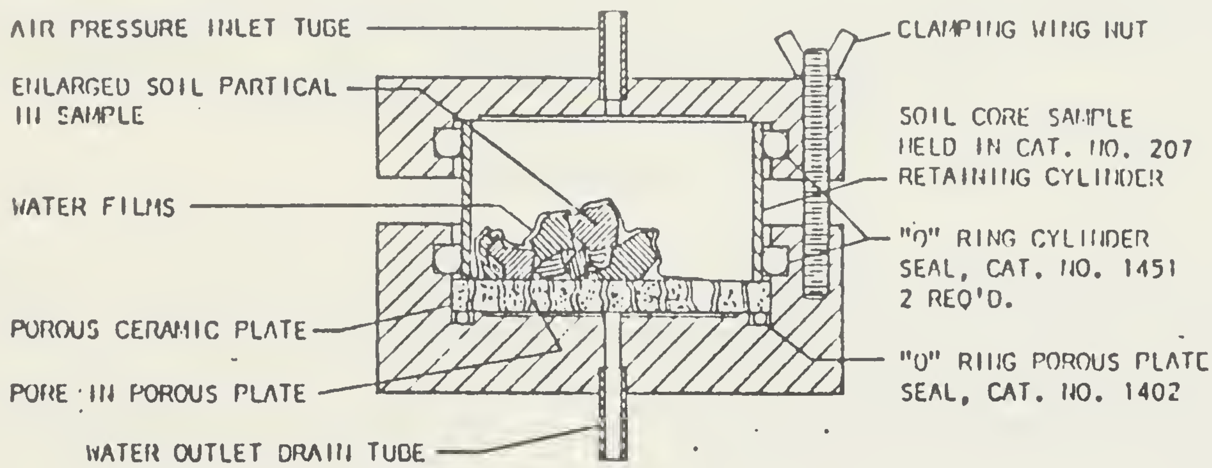

Figure 1. Schematic of the Tempe cell assembly used for column studies.

A control test was run on the upper soil profile (0 to 4 inch). This test used deionized water instead of the peroxide-treated barren solution. Control tests were composited in a single sample of approximately 1.5 pore volumes. This test was intended to provide an indication of the natural mobility of metals in the surface soils.

Each extract composite was measured for pH and electrical conductivity (EC). If necessary, samples were diluted to 150 ml to provide sufficient volume for analytical work. The diluted sample was split into a 30 ml base-stabilized sample (for cyanide analysis) and a 120 ml sample which was acidified with 0.1 ml of nitric acid (sample pH approximately 2.0) for metals analysis.

Samples of the barren leach solution (not acidified) and the peroxide-treated barren solution were also submitted for analysis together with the extract samples. Samples were analyzed for Cd, Cu, Pb, Mn, Ni, and Zn using ICP analysis. Selenium and As were analyzed using a hydride generation technique. Hg was analyzed using the cold vapor method. Total cyanide was measured using EPA method 335.3. Results of the analytical tests on barren solution, treated barren, and column leachates are shown in Figures 2 through 9.

RESULTS

Arsenic

The peroxide oxidation of cyanide resulted in virtually complete precipitation of arsenic. However, application of the arsenic-free barren to upper profile soil samples resulted in release of arsenic present in the soil (Figure 2). The control tests, also on upper profile soils, produced even higher arsenic levels in extracts, roughly twice that obtained with the barren leach solution. The high oxidation potential of the peroxide treated solution may have been an important factor in limiting arsenic resolubilization. Arsenate ion, the most completely oxidized form of arsenic, forms very insoluble compounds with several soil minerals including iron hydroxides which is abundant in soils.

Lower profile soils did not show any arsenic release (all samples were below detection limits). Whether this is due to the initially low arsenic levels in subsurface soils or the ability of these soils to retain arsenic is unclear from the data. However, it is clear that a LAD system will not result in excessive arsenic in leachate.

Cadmium

Cadmium was effectively precipitated by peroxide treatment to below the analytical detection limits. Control tests showed some release from the surface soils at a concentration of about 3 ppb. However, none of the soil samples contacted with treated barren showed any cadmium in the extract. Thus, contrary to conclusions drawn in earlier work, cadmium should not be present in significant quantities in leachate below a LAD system.

Copper

Copper was precipitated by peroxide treatment with 98 percent efficiency. However, a residual soluble copper content of over 2 ppm remained in the treated barren. The upper profile soils were remarkably effective (Figure 3) at reducing this residual metal content often to below the detection limit of 10 ppb. Lower profile soils performed well also but did not achieve the high level of control shown in the upper profile.

Control tests produced quite high Cu levels. This particular test was the only test to produce a slightly cloudy extract. We suspect that there was a small leak allowing a little particulate matter into the sample. This may have contributed to the high copper analysis reported. The data for this particular test should be interpreted with caution. Copper will be very effectively treated in a LAD system.

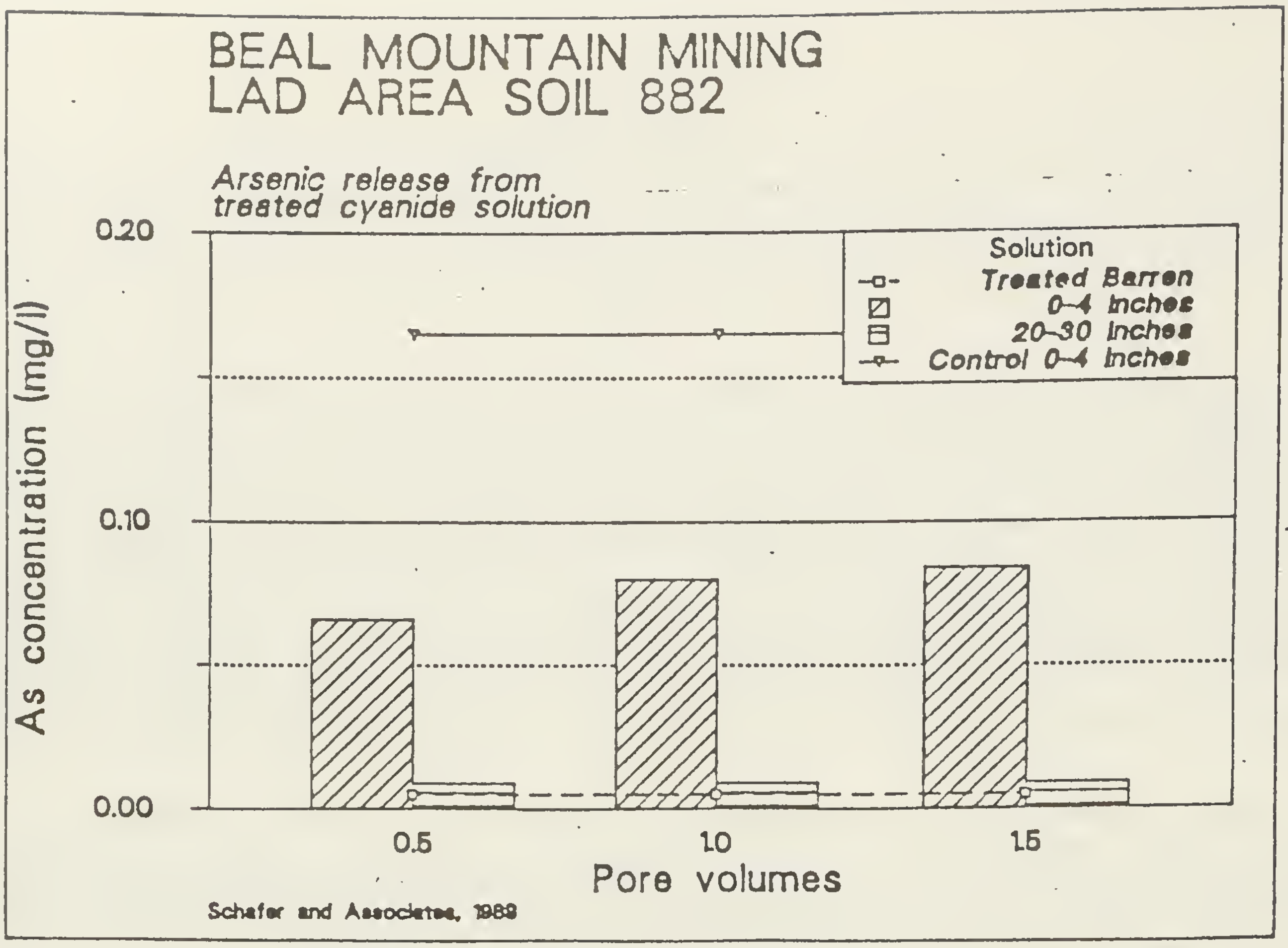

Figure 2. Arsenic levels in cyanide solution leachate applied to soils.

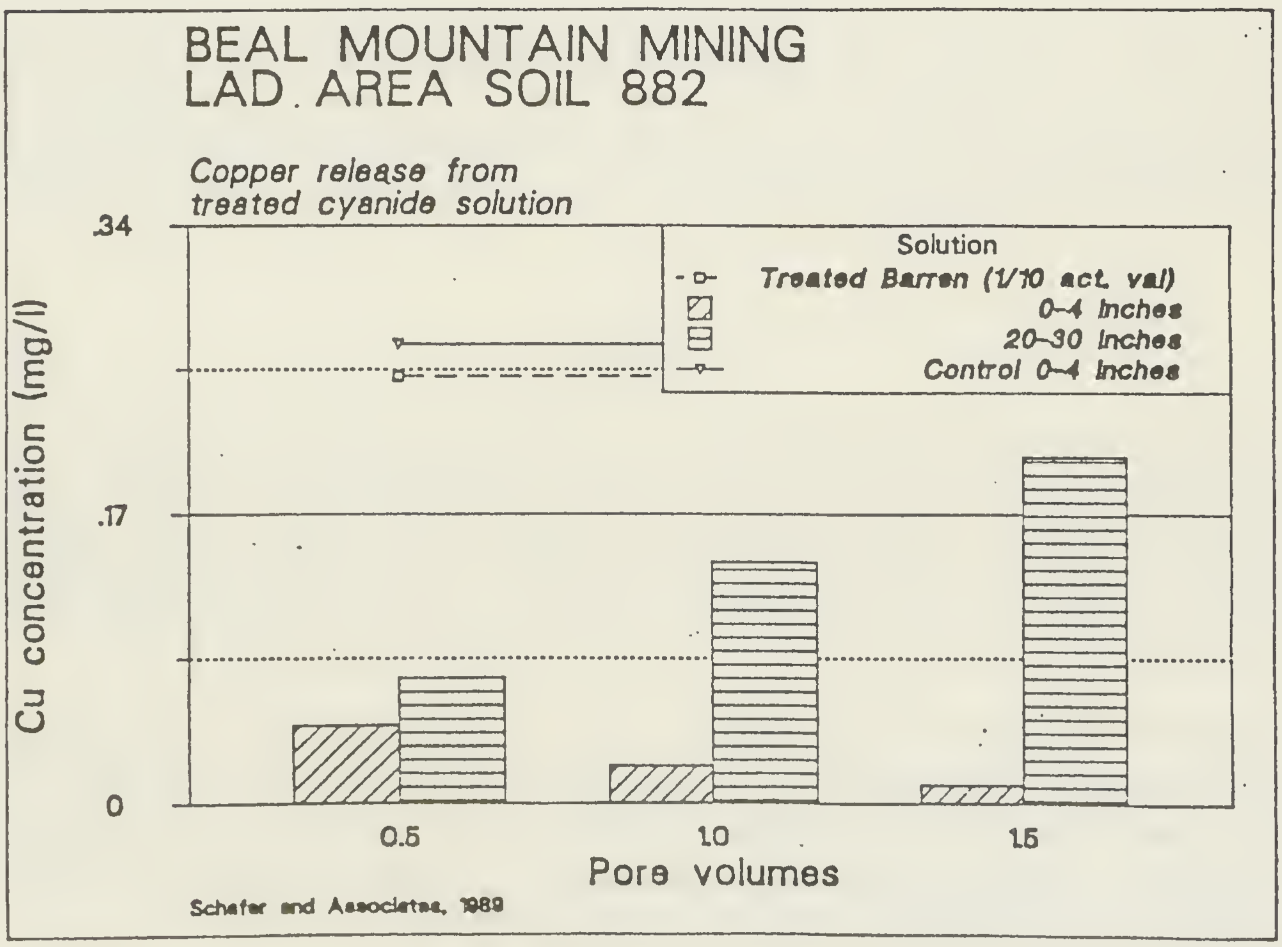

Figure 3. Copper levels in cyanide solution leachate applied to soils.

Lead

Lead was below analytical detection limits in both the barren and treated barren solutions and in all soil extracts using the treated barren solution. Control tests did show extract lead levels slightly higher than instrument detection limits. Lead will not be a problem for a LAD system at Beal Mountain.

Mercury

Mercury was detected at low levels in the barren leach solution. Treatment with peroxide reduced the mercury content by approximately 70 percent to a level of 3 ppb. Application of the treated solution to soil samples reduced mercury levels to less than detection limits in all cases. Controls did not show measurable mercury release as was observed with a number of other elements. Mercury will be effectively controlled by the proposed LAD system.

Manganese

Manganese was present in low concentrations in the barren leach solution (Figure 4) and was reduced to less than 2 ppb by peroxide treatment. However, application of the treated solution to soil samples resulted in release of significant quantities of manganese from the soils, particularly from the 0 to 4 inch soil profile. Although the concentrations observed are less than those from the previous study, the general response is confirmed. The control tests did not show significant levels of manganese release. The concentration of manganese in extracts from the upper profile soils was always higher than from the lower soil profile.

A possible explanation of the observed increase in manganese follows. Manganese may be present in an exchangeable form. If this is the case, metals like copper and nickel may be preferentially adsorbed to soil exchange sites and could displace manganese. This hypothesis fits well with the observation that other metals are removed in the upper soil profile while manganese is solubilized.

While this mechanism explains how a soluble manganese form may appear it does not explain how it remains soluble. The stability diagram for manganese minerals (Figure 5) provides some insight on this. Only under the most highly oxidizing conditions (equilibrium with atmospheric oxygen, pe + pH = 20.61) is it possible to form highly insoluble forms of manganese, pyrolusite and manganite. Most surface soils are able to sustain a pe + pH of 16. Under these conditions a mixture of $MnOOH$ and Mn_3O_4 is the stable solid form. The solubility of these materials is approximately 10^{-5} $\underline{M}$ Mn^{+2} or about 0.55 ppm. This is comparable to the measured values we obtained in the soil extracts. Hence, the observed soil manganese levels we observed appear to be typical of most natural soils.

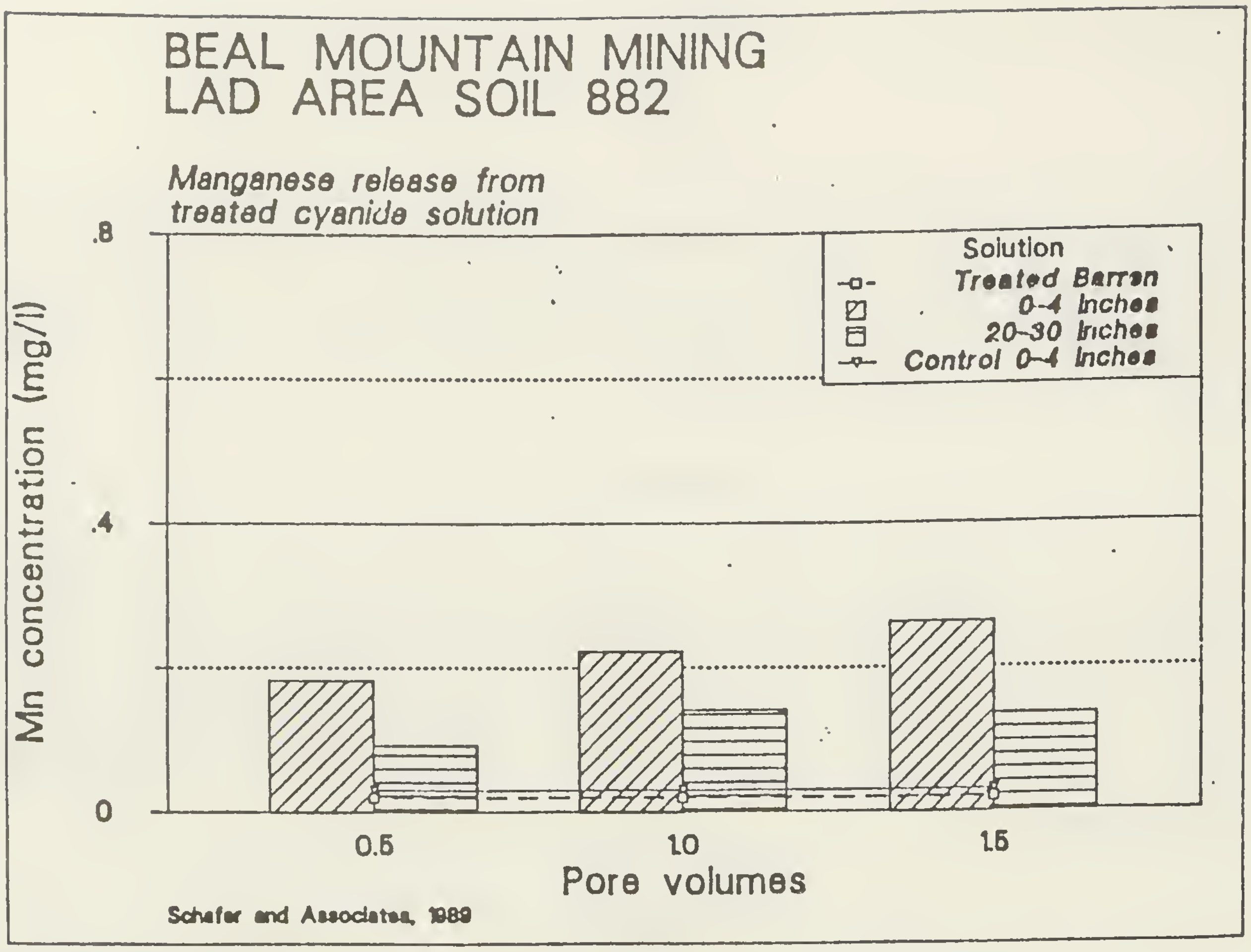

Figure 4. Manganese levels in cyanide solution leachate applied to soils.

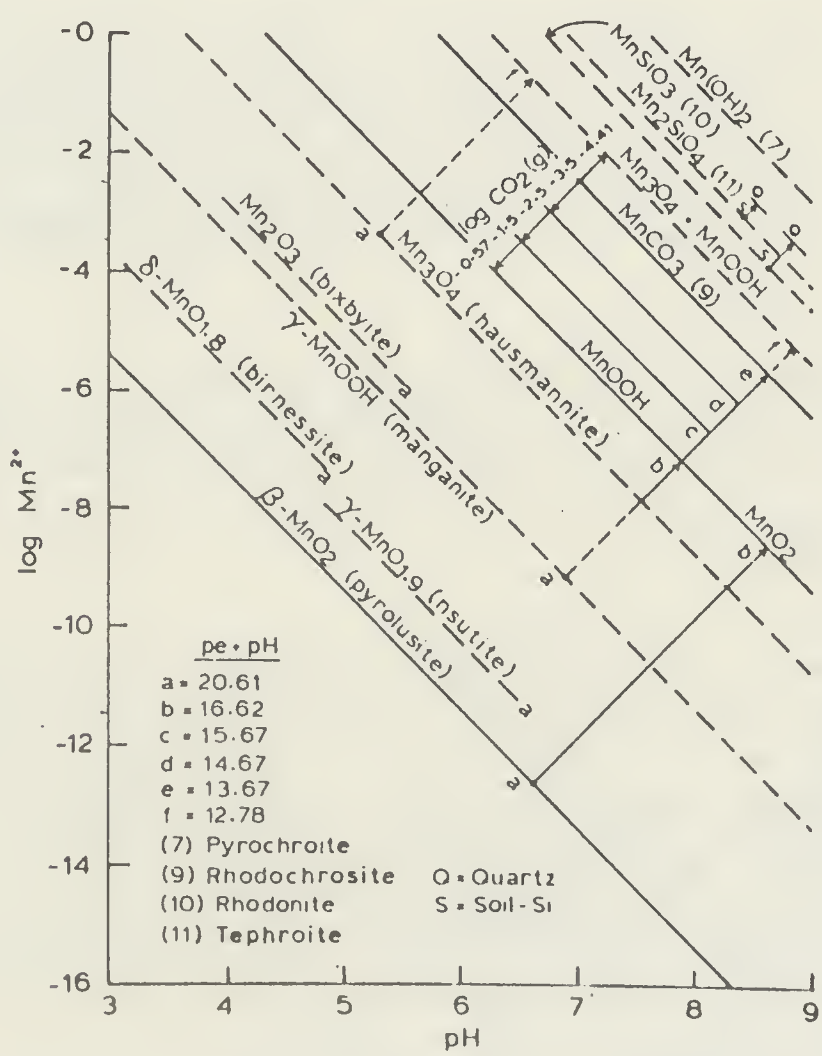

Figure 5. Solubility diagram for manganese minerals found in soils (from Lindsay, 1979)

In spite of clear indication of mobilized manganese in these laboratory tests, it is not certain that manganese represents a serious problem for a LAD system at Beal Mountain. Most of the lower profile soil extracts are only marginally higher than Secondary Drinking Water Standards; manganese released from the upper profile may be removed as it passes through the lower profile.

Nickel

Nickel was present in the barren solution at a level of approximately 1.3 ppm and was reduced to .29 ppm by peroxide treatment. Additional attenuation, typically to less than the MCL standard of 0.1 ppm, was obtained with application to the soils (Figure 6). The upper profile soil was somewhat more effective in removing nickel than the lower profile soils. Nickel should be adequately controlled by a LAD system.

Selenium

Selenium was found in the barren solution at a concentration of .35 ppm and was not effectively removed by peroxide treatment. Both the upper profile soils and the lower profile soils were able to remove approximately 50 percent (Figure 7) of the Se in the two inch column depth of the Tempe cell. This data is encouraging since previous tests indicated that extract selenium values in leachate were actually higher than in the treated barren solution.

Recent work with selenium in soils by Bar-Yosef and Meek (1987) indicates that adsorption is an important mechanism only at low selenium levels and that selenium is very mobile at high concentrations, especially in the selenate form. Based on the data of Bar-Yosef and Meek and the measured selenium concentrations of the soil extracts, adsorption would be very important if selenium were present as selenite and at least a significant factor in overall solubility if it is present as selenate. It is probable that the greater soil depths available in the field will result in continued improvement in selenium removal. If the first two inches achieves a 50 percent removal, the next two inches might be expected to reduce the balance by 50 percent and so on. Thus, effective selenium fixation may be possible with the LAD system. However, field testing may be necessary to confirm this.

Zinc

Zinc was present in barren leach solution at 0.46 ppm and was totally precipitated by peroxide treatment. Like manganese, zinc was solubilized from the soils by the treated barren solution (Figure 8). Unlike manganese, the highest zinc release was in the first extract. This may be indicative of the depletion of extractable zinc from the soil. Typically, about 30 percent of available ammonium acetate extractable zinc was recovered from the surface soils where its concentration is relatively high. Percentage recovery of ammonium acetate extractable zinc appeared to be even higher from the lower profile

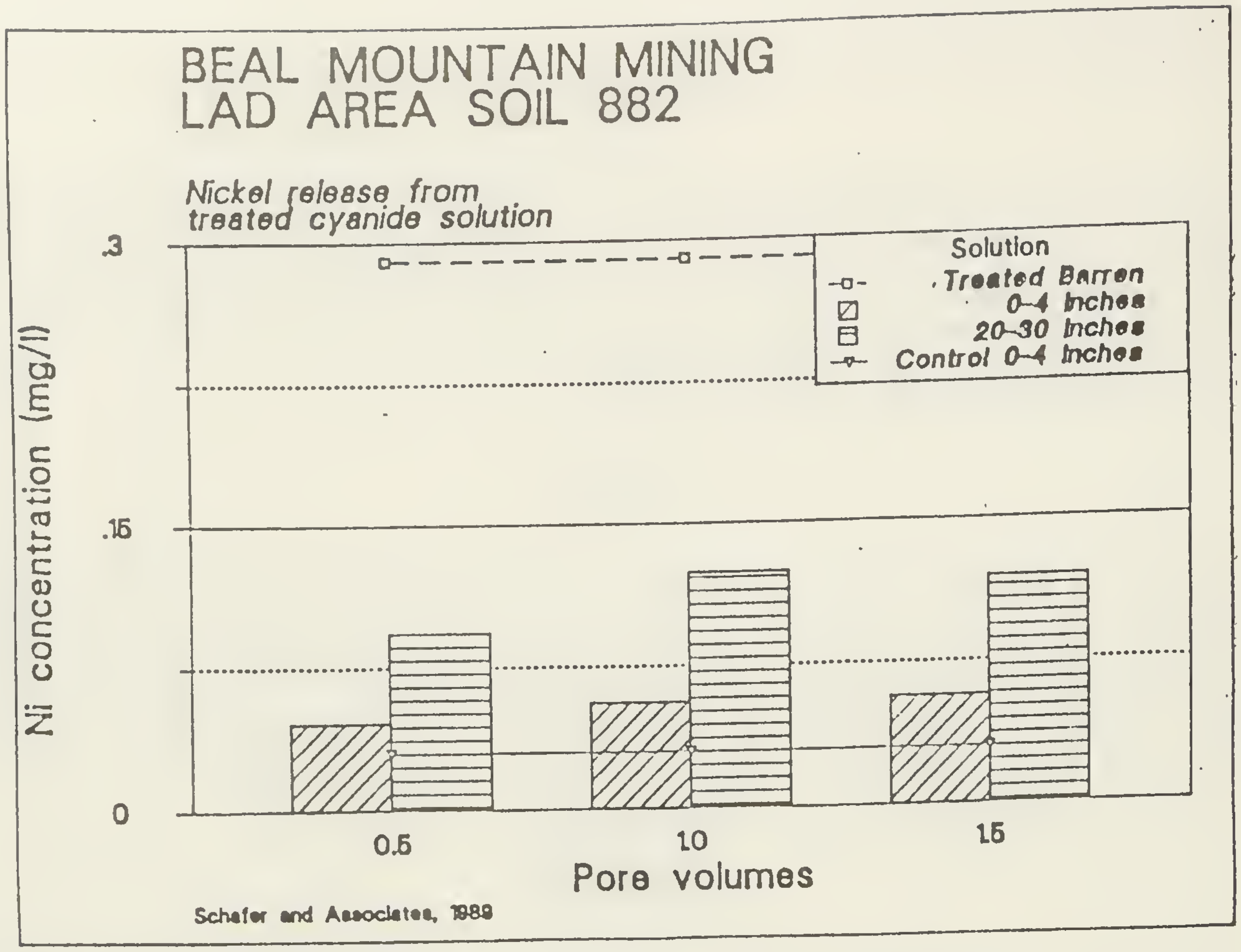

Figure 6. Nickel levels in cyanide solution leachate applied to soils.

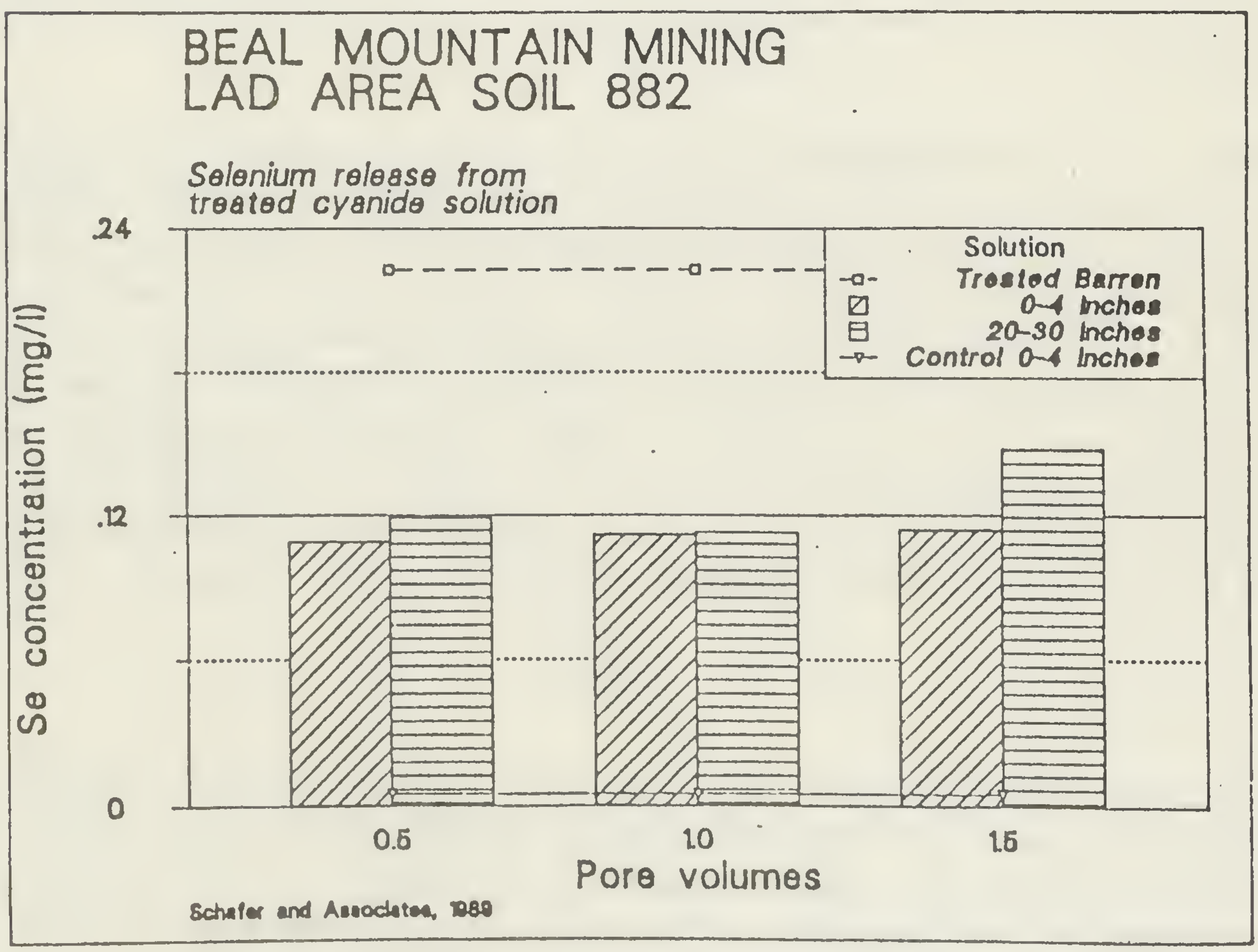

Figure 7. Selenium levels in cyanide solution leachate applied to soils.

soils. However, even control tests showed significant release of zinc at up to .1 ppm in soil extracts.

The concentration of zinc in extracts was never higher than 0.25 ppm. This concentration should not produce significant deterioration of water quality due to use of the LAD method.

Cyanide

Approximately 96 percent of total cyanide was destroyed by treatment with peroxide. Residual total cyanide was present at a concentration of 12.7 ppm. This degree of cyanide destruction is typical of peroxide treatment (Smith, 1988). Free cyanide, not assayed in this study is typically under 0.1 ppm following peroxide treatment. Most residual cyanide is present as stable metal complexes, copper, nickel, and cobalt being the most significant for Beal Mountain.

The attenuation of cyanide by soils is not significant (Figure 9). In fact, test results tend to show slightly higher total cyanide in soil extracts than in the treated barren solution applied. A explanation for this observation is not apparent; the observation may not be statistically significant.

The inability of the peroxide treatment/LAD combination to effectively destroy or immobilize cyanide to levels less than 10 ppm is a matter of concern. We are not certain what form the cyanide takes as it passes through the soil. Most of the metals which we believe are effectively complexing cyanide are removed in the soil. These metals may be replaced by iron, an element we have not analyzed, which tends to form extremely stable cyanide complexes. Or they may be replaced by calcium, magnesium, sodium, and potassium which are more soluble cyanide compounds.

Cyanide removal may be improved as retention time of solution in soil increases. If free or weak-acid dissociable cyanide in re-generated in soil systems, these compounds may biodegrade or volatilize in time. Aerobic biological systems typical of soils are able to biodegrade free cyanide up to 100 ppm or more. Only anaerobic systems are affected by low levels of free cyanide. If cyanide degradation does not occur rapidly in soils, alternative cyanide destruction methods could be considered. Secondary treatment methods for residual cyanide which are more effective than peroxide at low cyanide concentrations are available including chlorine dioxide treatment.

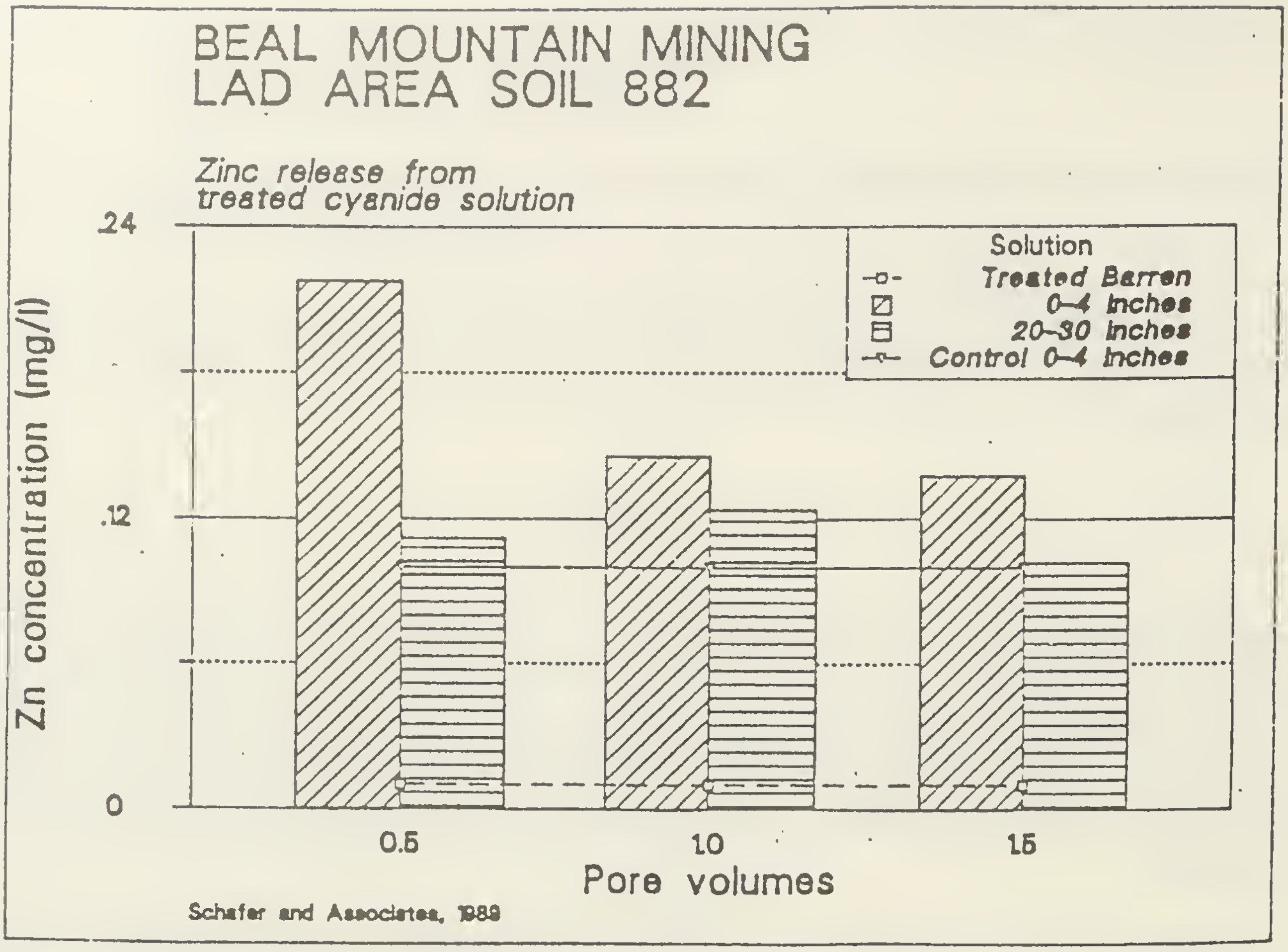

Figure 8. Zinc levels in cyanide solution leachate applied to soils.

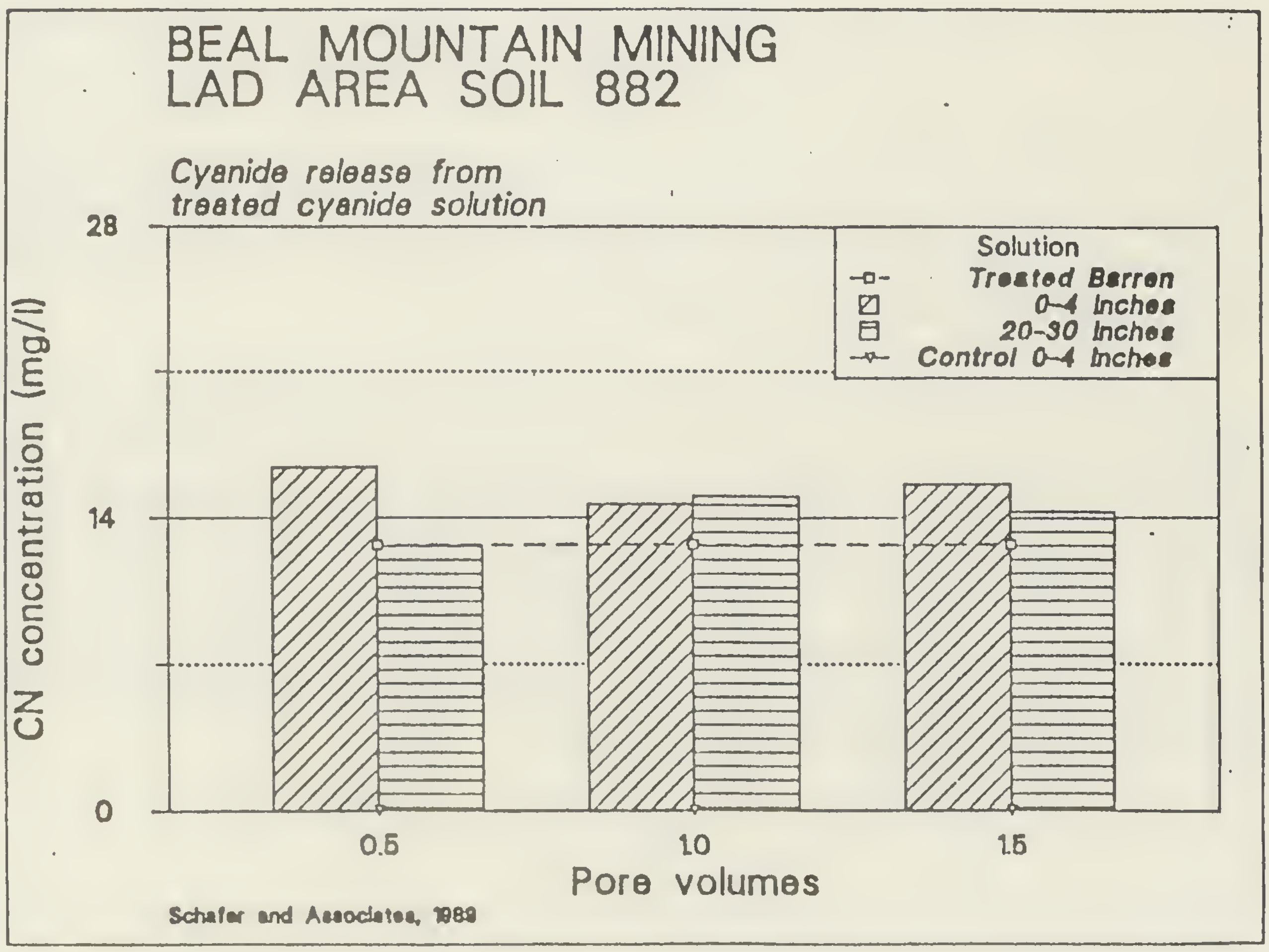

Figure 9. Cyanide levels in cyanide solution leachate applied to soils.

Summary

The laboratory test results indicate that most metals in the barren leach solution will be precipitated by peroxide treatment or attenuated by the soils within the LAB area. Cadmium, which had been indicated in previous tests as a potentially mobile metal was completely controlled in these tests. Selenium, which had shown a tendency to solubilize from the soils in the proposed LAD areas, was not solubilized in these tests. This metal was not effectively removed by peroxide treatment, but partial attenuation was obtained in the two inch soil column used for the bench scale tests. It is anticipated that field application to soils with several times this depth in effective treatment volume will provide a satisfactory level of control. Manganese responded in the surface soils much as it did in the earlier tests, producing a substantial release into the applied leach solution. Lower levels of Mn were released from subsurface soils. Manganese levels appeared to be within the expected range for soil solutions, however.

We analyzed for total cyanide in our column tests whereas previous work measured only free cyanide and weak acid dissociable (WAD) cyanide and then only in the treated barren solution. Total cyanide was present in the destructed barren solution at a concentration of 12.7 ppm. This level is typical of hydrogen peroxide treatment. Residual cyanide is likely present as strongly complexed metal cyanides. The cyanide did not appear to be attenuated by soils at all. What is somewhat disturbing is that most of the metals suspected of complexing this cyanide are attenuated by soils, suggesting that free cyanide may be re-generated in soil systems.

Some metals like Cu and Ni were removed best in surface soils which had an abundance of organic exchange sites. Other metals notably As, Mn, and Zn were attenuated best in subsurface soils which are typically enriched in clays, and iron and aluminum oxide minerals. Use of undisturbed soils appears to provide a well-suited heterogenous treatment media for metal removal from process solutions with a complex suite of metals. The relative effect of the soil system on metal removal is summarized in Table 2. The relationship of metal concentration in leachate to levels in the treated barren solution and in the distilled water leachate is shown. Typically metal levels were similar to or slightly higher than in leachate from distilled water but substantially lower process solution (i.e. Ni, Se, Hg, Pb, Cd). For a few metals, leachate levels were lower than the distilled water leach (Cu, and As) perhaps due to the oxidizing effect of the treated process solution on metal solubility. Levels of Mn and Zn were higher in leachate than either the process solution of the ditilled water leach. This may have been due to exchange of more strongly soil-adsorbed metals (Cu, Ni, Hg) for more weakly held ones (Mn, Zn). Finally, cyanide was not attenuated in soils effectively.

Table 2. Metal levels in leachate, treated barren solution, and in distilled water leachate.

Element	Leachate Concentration Compared to: Treated Barren	Distilled Water Leachate
As	+	-
Cu	-	-
Mn	+	+
Ni	-	+
Se	-	+
Zn	+	+
En	same	+
Pb	nd	-
Cd	nd	-
Hg	-	nd

nd - comparison not determined, metal concentrations near detection limit.

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Lindsay, W.L. 1979. Chemical Equilibria in Soils. John Wiley and Sons. New York.449 pgs.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

DESIGN AND OPERATION OF LAND APPLICATION DISCHARGE SYSTEMS FOR MINERAL PROCESSING EFFLUENT

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ABSTRACT

Land Application Discharge (LAD) is becoming recognized as a preferable option for the ultimate disposal of treated cyanide processing effluent from precious metal extraction. This paper discusses LAD design methodology, site selection, baseline criteria, and laboratory testing procedures. It is concluded that chemical treatment of cyanide prior to LAD may be unnecessary and, in certain cases, environmentally detrimental.

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INTRODUCTION

Land Application Discharge (LAD) offers an acceptable method for ultimate disposal of treated cyanide effluent. LAD involves the sprinkling of treated water on a designated area, allowing the soil to attenuate residual cyanide and metals. The application rate is controlled to prevent deep infiltration and maximize soil/water contact time. Proper land application requires knowledge of the chemistry of the water, the capability of the soils to remove contaminants, and the water holding capacity of the soils. LAD is typically restricted to times when soils are capable of accepting additional water without generating overland flow. In Montana this restricts LAD use to late spring through late fall when the ground is neither saturated, snow covered, or frozen.

In the past, the Montana regulatory agencies have not viewed LAD as part of the treatment system and used cyanide content of the effluent as the primary criteria for discharge. Past practice required cyanide to be reduced to extremely low levels (0.05 ppm weak acid dissociable prior to LAD). Recently the Water Quality Bureau (WQB) has stated that cyanide in the groundwater must remain below the EPA recommended drinking water level (0.22 ppm free) at the property or permit boundary. The change in acceptable cyanide concentrations by the WQB allows focus on environmental chemistry in addition to effluent chemistry. This recent administrative change forces both the agency and operator to evaluate other important characteristics (e.g. metals, sodium, and pH) of the discharge solution rather than just cyanide concentration.

LAD SYSTEM DESIGN

Initial design of a LAD System requires soil mapping, soil analyses, and soil column tests. In addition, vegetation and weather information is needed to estimate the application rate. Suitable LAD sites are those exhibiting well developed soil profiles, moderate slopes, and located proximal to the site.

Representative soils from the proposed site(s) are sampled and typically analyzed for the following:

pH	Arsenic	Electrical Conductivity
Cadmium	Copper	Sodium Absorption Ratio
Copper	Iron	Cation Exchange Capacity
Calcium	Manganese	Magnesium
Mercury	Sodium	Zinc
Texture	Organic Matter	Cyanide (total)

Textural classification is important when consideration is given to field capacity, cation exchange capacity, and sodium adsorption ratio of the soils. Control of sodium in discharge solutions is critical to preventing dispersion of the clay particles and damage to the soil structure in soils with excessive clay. Maintenance of the soil structure is vital to continued use of the LAD site.

Moisture retention and the metal attenuation capacity of a soil are important criteria. Column attenuation tests are conducted on typical soils collected from the proposed LAD site. A metals rich solution is prepared, the solution is applied to the columns in the laboratory, and the collected leachate analyzed for metals and compared with the applied solutions.

Careful consideration should be given to the design of the test solution. During treatment the effluent my be modified by dilution, alkaline chlorination, peroxide addition and acidification before it is discharged. Ranges of pH between 6.5-8.5 are considered acceptable for most LAD sites. Therefore, pH control is a necessary part of treatment and the metals concentrations in the test solution should be selected according to metals concentrations at the expected pH. However, if the expected metals concentrations are near the groundwater background levels, they should be increased in the test solution in order to demonstrate the metals attenuation capacity of the soils.

Three diverse sites were selected for comparing metal attenuation capabilities in soil. The sites represent LAD areas for proposed mining operations.

As indicated on Table 1, most metals at the three example sites were reduced below detection levels in the leachate. This is a common result in tests of this type and indicates the effectiveness of the soil to attenuate metals.

Land application should proceed at a rate that prevents deep infiltration of the water. For design purposes, this can be estimated by determining field capacity of the soil. Additional moisture capacity is available through evapotranspiration. Evapotranspiration can be estimated from vegetation type and weather conditions during land application. Obviously, precipitation during actual land application may greatly reduce the available soil capacity and land application should be suspended during significant rainfalls.

TABLE 1

SOIL COLUMN ATTENUATION TEST RESULTS FOR THREE SELECTED LOCATIONS

		Soil Column Leachate				
	Initial Prepared Solution	Column 1	Column 2	Column 3	Column 4	Column 5
Site A						
Total Metals, mg/l						
pH, standard units	8.0	7.8	7.8	7.4		
Arsenic as As, mg/l	0.56	0.015	<0.005	0.108		
Cadmium as Cd, mg/l	0.44	0.007	<0.005	<0.005		
Copper as Cu, mg/l	0.38	<0.02	<0.02	<0.02		
Mercury as Hg, mg/l	0.0016	0.0015	<0.0005	0.0016		
Zinc as Zn, mg/l	0.35	0.03	<0.02	<0.02		
Site B						
Total Metals, mg/l						
pH, standard units	6.4	7.2	7.4	7.6	7.1	
Arsenic as As, mg/l	0.56	<0.005	<0.005	<0.005	<0.005	
Cadmium as Cd, mg/l	0.53	<0.005	<0.005	<0.005	<0.005	
Copper as Cu, mg/l	0.43	<0.02	<0.02	<0.02	<0.02	
Mercury as Hg, mg/l	0.0012	0.0013	<0.001	<0.005	<0.001	
Zinc as Zn, mg/l	0.53	<0.02	<0.02	<0.02	<0.02	
Site C						
Total Metals, mg/l						
ph, standard units	3.5	6.5	6.3	5.9	6.2*	5.6
Arsenic as As	0.550	0.007	0.008	<0.005	0.023	<0.005
Cadmium as Cd	0.433	<0.005	<0.005	<0.005	0.007	<0.005
Copper as Cu	0.43	<0.02	<0.02	<0.02	0.02	<0.02
Silver as Ag	0.03	0.02	<0.02	<0.02	0.04	<0.02
Zinc as Zn	0.45	0.05	<0.02	<0.02	0.12	0.02

* The leaching solution appeared to channel through the column

(<) indicates less than method detection limit

Soil field capacity is estimated during initial studies from the column tests. The field capacity is approximately equal to the amount of water applied to the soil columns minus the leachate volume. For the following example LAD site (Site B), this amount averaged 430 ml for the five centimeter diameter columns, which is equivalent to 8.35 inches of water. Note that the antecedent soil moisture is, in effect, already subtracted because the initial condition of the soils included natural moisture.

Evapotranspiration can be estimated from evaporation at the site using a monthly consumptive use equation, for example:

$$U = k(E + 2.70) \quad \text{(Chow, 1964)}$$

where U = monthly consumptive use (inches)
k = monthly consumptive use coefficient
E = monthly pan evaporation (inches)

Monthly evaporation data for example Site B was established by Potts (1986). Typical monthly consumptive use coefficients are found in Chow (1964), and are 0.31 for pasture land during summer months. Precipitation is subtracted from the consumptive use to provide the net uptake of applied water by evaportranspiration. Table 2 summarizes the calculation of net evaportranspiration for example Site B during the summer months.

TABLE 2

CALCULATION OF EVAPORTRANSPIRATION FOR LAD SITE B
(inches)

	July	August	September	Total
Evaporation	6.10	5.94	4.45	16.49
Consumptive Use	2.73	2.68	2.22	7.63
Precipitation	-1.19	-1.26	-1.33	-3.78
Net evaportranspiration	1.54	1.42	0.89	3.85

The total amount of water that can be applied to this site is the field capacity plus the net evaportranspiration, 8.35 inches plus 3.85 inches equals 12.2 inches.

SUMMARY AND RECOMMENDATIONS

Land application discharge system design has involved the collection of soils and vegetation information combined with metal attenuation studies conducted in the laboratory. Much of the regulatory agency focus has been directed at cyanide concentrations before the solution is applied to the land.

Other aspects of the treated process solution, such as sodium, chlorine, pH and nitrate concentrations, do not typically receive the attention they warrant.

The soil environment represents the second stage in solution treatment for LAD systems. Dispersal of neutralized cyanide process solutions with proper levels of sodium, chlorine, nitrate and pH will protect the soil, vegetation, and water resources of the selected site.

Literature information regarding metal toxicity to range and forest plants is limited. The present belief is that most LAD systems will be sodium limited, and the sodium absorption ration (SAR) of the receiving soil is a major controlling factor. However, metal attenuation capability of soil requires more detailed study.

Research activities should be directed toward establishing the controls on LAD systems from the standpoint of phytotoxicity, metals movement, and nutrient loading in the soil profile.

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CYANIDE NEUTRALIZATION AND RECLAMATION OF HEAP LEACH PROJECTS

Debra W. Struhsacker [1] and Adrian Smith [2]

ABSTRACT

Reclaiming spent cyanided heaps is a two-step process consisting of chemical and physical reclamation. The first step is chemical reclamation in which the cyanide in the heap is neutralized by rinsing. Once the heap is neutralized to a prescribed regulatory standard, physical reclamation can begin, and the heap is recontoured and revegetated.

Regulatory standards for cyanide neutralization are typically established by state regulatory agencies with authority over environmental protection and water quality. Cyanide neutralization requirements are generally stipulated in the permit which is required for a heap leach project. In some states this permit contains a financial assurance provision which secures funds for the chemical reclamation phase of project closure. This bond is separate from and in addition to the bond held for surface disturbance of the heap leach area.

Regulatory requirements for cyanide neutralization vary from state to state. Some states base their requirements on drinking water standards, whereas others use more stringent standards such as aquatic biota criteria. Several states use site-specific conditions to determine neutralization requirements. Depending upon site characteristics and the nature of the potential receiving water, neutralization requirements may thus be more or less stringent than a given water quality criteria. Total cyanide, free cyanide, and weak acid dissociable cyanide are the cyanide species most frequently specified in cyanide neutralization regulations.

There are several methods for neutralizing cyanided heaps including fresh water rinsing, and a variety of chemical methods. Fresh water rinsing has the advantage of low reagent cost but may be time consuming and generate large volumes of contaminated water. Chemical methods tend to be faster than fresh water rinsing but have higher reagent costs and can generate environmentally problematic by-products.

There is a limited but growing body of laboratory and field data documenting the cyanide neutralization characteristics of leached ore. These data indicate that most cyanided ores can be effectively neutralized using fresh water rinsing, chemical treatment methods, or a combination of both. Fine-grained, porous, or agglomerated ores appear to be more difficult to neutralize. During neutralization, fine-grained or porous ores commonly exhibit a delayed release of cyanide due to physical flow and chemical diffusion processes. Cyanide levels in rinsed agglomerated ores can be reduced to meet regulatory requirements, but the resulting effluents commonly have elevated pH due to buffering by the lime in the system.

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CYANIDE NEUTRALIZATION AS A RECLAMATION ISSUE

Heap leaching is a precious metal recovery method being used successfully in many mining operations throughout the country. This method involves placing ore on impervious lined pads, percolating a dilute, high-pH solution of sodium cyanide through the heaps of ore to dissolve the gold and silver, collecting the metal-rich solutions in lined ponds, and processing these solutions to recover the precious metals. The spent ore heaps produced by heap leaching contain process chemicals both in interstitial pore water in the heap and on the surface of the ore. Additionally constituents leached from the ore, typically metals, may also be present.

Reclamation efforts for spent cyanided heaps must thus consider the chemistry of the spent heap as well as the more traditional aspects of reclamation, and reclamation of a heap leach facility is therefore a two-step process. The first step in the process is a chemical reclamation step to neutralize the cyanide used in the heap leach process. The ultimate purpose of this step is to modify the chemistry of the spent heap so that any runoff or seepage from the reclaimed heap has minimal potential to degrade surface water and ground water. The second step in the reclamation process is physical reclamation to recontour, topsoil, and revegetate the heap leach facility. The objective of this step is to produce a visually acceptable and functionally compatible landform within the context of the surrounding area.

Regulatory Requirements for Reclaiming a Heap Leach Facility

A number of federal, state, and local permits and approvals are required in order to construct, operate, and decommission a heap leach facility in most states. Generally speaking, there are two state agencies involved in determining reclamation requirements and obtaining financial assurance for heap leach reclamation.

In most states, chemical reclamation requirements and cyanide neutralization criteria are specified in the water quality permit required to build and operate a heap leach facility. In addition to neutralization requirements, these permits also specify design, construction, operational and monitoring criteria. Water quality permits for heap leach projects usually fall under the purview of the state agency responsible for environmental quality and protection. The permit requirements in many states for a heap leach facility also include a bonding provision to cover the cost of rinsing and neutralizing the heaps. Release of this bond is tied to neutralizing the spent heaps to a specified standard as well as meeting other reclamation requirements.

Most states have a separate permitting and bonding requirement governing the physical reclamation of a heap leach facility. Typically this permit and bond are administered by the state regulatory agency responsible for mine land reclamation. In projects developed on federal land, the permit and bonding authority for physical reclamation is generally shared by the state with the federal land management agency (i.e., the U. S. Bureau of Land Management or the U. S. Forest Service).

Cyanide Neutralization Requirements

Smith and Struhsacker (1988) present the results of a survey of regulatory officials from 14 states concerning maximum allowable residual cyanide concentrations in spent heaps. A wide diversity of responses was received in this survey, and no two states have identical regulations. However, some generalizations about the survey data can be made. In all

cases, the neutralization requirements are intended to ensure nondegradation of water resources.

A number of states have adopted a universally applicable cyanide neutralization standard which spent heaps must meet prior to physical reclamation. Those states with little or no experience with heap leach projects typically adopt default values for cyanide neutralization based upon existing water quality criteria such as the EPA drinking water guideline of 0.2 mg/l total cyanide or other water quality criteria. Oregon, an example of a state with no active heap leach projects, has indicated that operators may be faced with very stringent neutralization requirements in order to meet the aquatic biota water quality criterion of 0.05 mg/l total cyanide.

In states with more experience in regulating heap leach projects, cyanide neutralization requirements tend to be determined on a case-by-case basis depending on site-specific conditions. For example, Idaho recently enacted regulations for ore processing by cyanidation in response to the growing number of heap leach projects in the state. The new Idaho regulations do not stipulate a specific neutralization standard, but require operators to reduce cyanide and other pollutants in water draining from the heap "to a level that is based on the disposal method, location and the potential for ground water and surface water contamination". In this manner, cyanide neutralization requirements for a specific project in Idaho could be more or less stringent than drinking water standards depending upon the quality and use designation of the potential receiving water. The new Idaho regulations also include a pH criterion for spent heaps, and require that water draining from a heap fall within the pH range of 6.5 to 9.0.

Like Idaho, Nevada has also recently enacted new regulations for the design, operation, and closure of heap leach facilities. The new Nevada regulations specify a cyanide neutralization criterion of 0.2 mg/l weak acid dissociable cyanide and a pH level between 6.0 and 9.0. Although the Nevada regulations establish a cyanide neutralization standard, they also leave room for consideration of site specific conditions. If an operator cannot achieve the established standard, a variance can be obtained. In requesting a variance, an operator must prove that the residual cyanide in the solids will not become mobile, or that the material in the heap can be stabilized so "to inhibit" meteoric water from penetrating and percolating through the heap.

Those states which do consider site specificity in setting neutralization requirements generally try to select reclamation procedures and neutralization and abandonment requirements appropriate for the project site. When site conditions are taken into consideration, it becomes apparent in many cases that it is impractical and unnecessary to impose drinking water guidelines for neutralized heaps. The environmental sensitivity of the project site may not warrant such stringent requirements. Furthermore, it may be costly, if not impossible, to neutralize to a drinking water guideline.

There is no consensus of opinion among the states surveyed concerning the cyanide species and cyanide analytical procedures specified in the regulations. Some of the states express their cyanide requirements in terms of free cyanide, whereas others have standards defined in terms of total cyanide. Idaho and Nevada, the two states with the most recently promulgated regulations, express cyanide neutralization requirements in terms of weak acid dissociable cyanide. Free cyanide is also an acceptable criterion in Idaho, but the Idaho Department of Health and Welfare, the governing regulatory agency, has expressed preference for weak acid dissociable analyses (IDHW, 1987). The apparent trend favoring weak acid dissociable cyanide analyses is based upon the growing awareness of potential

analytical problems associated with free cyanide and total cyanide analyses (Smith and Struhsacker, 1988). An example of these analytical problems is presented below in the section on available neutralization data for cyanided heaps.

Although most states express cyanide neutralization requirements in terms of the cyanide concentration in the effluent draining from the heap, some states have standards based upon the cyanide remaining in the heap. For example, California and South Dakota require solid extraction tests to measure residual cyanide concentrations in the heap.

Cyanide Neutralization Bonding Requirements

The permitting requirements for heap leach projects also include a bonding provision in some states. Oregon, for example, recently drafted legislation which establishes the State's authority to require a bond for all cyanide ore processing operations in order to insure funds for chemical reclamation. This bond ranges in amount from a minimum of $25,000 to a maximum of $500,000, and is in addition to the bond posted for reclamation of surface disturbance. Similarly, the new Idaho regulations also include a bond for cyanide neutralization which is in addition to the bond required for physical reclamation. The Idaho bonding provisions are based on the tonnage of ore under leach in a calendar year, with the minimum bond amount set at $25,000 and the maximum amount at $100,000.

Physical Reclamation Requirements

A complete discussion of the physical reclamation requirements for heap leach facilities is beyond the scope of this paper. Generally speaking, however, reclamation of surface disturbance in a heap leach area has the goal of creating recontoured, revegetated mounds of crushed rock which blend unobtrusively into the surrounding area. After the heap is completely rinsed, neutralized to meet state requirements, and drained, the heap is then ready for physical reclamation. Prior to physical reclamation, some states also require puncturing of the liner. During recontouring, the heap material is spread out to cover all earthworks and liner materials, the heap slopes are reduced to minimize erosion and visual contrast, and a natural, self-maintaining drainage is reestablished. After recontouring, the heap leach area is topsoiled and revegetated.

The pond areas are also reclaimed to blend into the surrounding topography. After the neutralized leach solution from the ponds is disposed of through spray evaporation, all pond liner materials are either removed or buried by folding the liner into the bottom of the pond and completely covering the liner with soil. The ponds are then filled with soil or rock material to prevent water pooling, contoured to blend into the surrounding topography, and reseeded.

THE GEOCHEMISTRY OF CYANIDE NEUTRALIZATION AND DEGRADATION

Smith and Struhsacker (1988) identify the cyanide species likely to be present in the heap environment, and describe the geochemistry of cyanide destruction and degradation. Many of the cyanide species remaining in the heap after neutralization are relatively stable and not toxic. Additionally, there are numerous geochemical processes within the heap which cause natural degradation of cyanide with time. Understanding these natural cyanide degradation mechanisms, and the mobility and toxicity of the cyanide species present in a neutralized heap, is key to evaluating the potential impacts associated with the cyanide remaining in a heap. Regulatory requirements for cyanide neutralization should be based

upon the significance of potential impacts due to residual cyanide in the heap, rather than mandating neutralization performance standards tied to an arbitrary water quality criteria.

Natural Methods of Cyanide Degradation

The prevailing geochemical conditions within the decommissioned heap environment vary for different parts of the system. The upper portions of the system, including the heap, the pad, and the underlying weathered bedrock, are likely to be oxidized and relatively dry or at least unsaturated. The underlying unweathered bedrock is commonly a reduced and saturated environment. The specific geochemical conditions within a heap leach system will be strongly influenced by site conditions such as the position of the water table, amount of precipitation on the heap, the mineralogy of the spent ore and of the underlying bedrock, and the fracture density and permeability of the bedrock (Smith and Struhsacker, 1988).

Numerous cyanide species exist within the decommissioned heap environment. Many of the cyanide species present are not toxic and are relatively stable complexes or compounds under most conditions. Some cyanide species, however, are not stable and react with the environment to produce hydrogen cyanide, a toxic form of cyanide. As described by Struhsacker and Smith (1988), there are a number of naturally occurring geochemical reactions within the heap environment which commonly degrade cyanide into less toxic or non-toxic compounds. Thus with time, the heap environment tends to be self-neutralizing, and the cyanide concentration will decrease.

In evaluating the environmental risks associated with allowing some residual cyanide to remain in a heap, it is important to consider the processes that contribute to natural degradation of cyanide following neutralization. Englehardt (1985) quantified the effectiveness of passive or natural degradation of cyanide in the heap environment by studying a heap in California which was abandoned without any rinsing. Englehardt documented that 85 percent of the cyanide present at the end of leaching had naturally degraded within 18 months after leaching ended. Extrapolating from these data, it would take approximately four years for that particular heap to attain the cyanide neutralization regulatory standard of one mg of total cyanide per one kilogram of ore prescribed by the state.

Operational Methods of Cyanide Neutralization

There are a variety of methods currently being used to neutralize cyanide during the decommissioning phases of a heap leach project. As described in detail by Smith (1988), these methods expedite naturally occurring mechanisms for cyanide destruction and degradation. The most frequently used procedure, fresh water rinsing, relies upon hydrolysis and volatilization as the processes for cyanide destruction. Other methods being used by some operators for cyanide destruction involve chemical treatment and include acidification, alkaline chlorination, the sulfur dioxide (INCO) oxidation process and the hydrogen peroxide (Degussa) process.

Cyanide destruction is generally accomplished during heap decommissioning by spraying or trickling the rinsing solution onto the heap using the same solution distribution system as is used during leaching. After the rinsing solution has percolated through the heap, it drains into one of the lined solution containment ponds, is treated if necessary to maintain the desired chemistry, and is recycled back onto the heap. Operators using a chemical treatment method for cyanide destruction typically add the neutralizing reagents to the solution in the pond, rather than applying the reagent directly onto the heap. If water is

the rinsing medium, it may be necessary to add incremental amounts of fresh water in order to maintain the necessary volume of solution and to dilute any soluble constituents dissolved from the heap by the rinsing solution. The neutralization solutions are recycled onto the heap until the effluent draining from the heap meets the established cyanide concentration and pH criteria.

Pros and Cons of the Various Cyanide Destruction Methods

Smith (1988) discusses the chemistry of cyanide destruction by the various methods and the operational and environmental pros and cons of these methods. Rinsing with fresh water obviously involves the lowest reagent cost because no chemical additions are used. Some operators modify the fresh rinsing process by adding an acid to lower the pH of the rinse water. This acidification step can expedite the neutralization process because the hydrolysis reaction controlling cyanide destruction is pH dependent (Struhsacker and Smith, 1988). The advantages associated with fresh water rinsing and acidification are low reagent cost, and the methods do not produce any potentially long-lived, toxic reaction products. The potential disadvantages of fresh water rinsing are that it may be slow, and it may produce large volumes of partially contaminated rinsing solution which then require possible chemical treatment and disposal. Generating large volumes of contaminated solution may be of particular concern for projects in seasonally wet climates in which a fairly stringent water balance must be achieved in order to maintain a zero-discharge operation.

The advantages of the various chemical treatment options for cyanide destruction include the increased speed with which most heaps can be neutralized compared to neutralization using only fresh water, and the more complete destruction of some metal-cyanide complexes (Griffiths, 1988, and Knorre and Griffiths, 1985). The most obvious disadvantage of chemical treatment methods is the high reagent cost involved. However, this cost needs to be measured against the increased operational costs potentially involved with the longer rinsing time and solution disposal costs associated with fresh water rinsing. Using chemical methods may introduce chemical constituents such as sodium, chlorine, and copper which, if released, may result in adverse impacts to the environment. For example, the alkaline chlorination process may produce toxic chlorinated organic compounds. Chlorinated organic compounds are potential carcinogens, and may pose long-term liability problems for an operator. Similarly, the use of a copper catalyst in both the sulfur dioxide and hydrogen peroxide methods may produce residual effluents with copper concentrations which exceed regulatory standards (Smith, 1988).

COLUMN RINSING TESTS

Some states are now encouraging or requiring permit applicants to provide cyanide neutralization data based on column rinsing tests as part of their permit application. Moreover, because cyanide neutralization considerations can influence project capital and operating costs, it is advisable to determine the cyanide neutralization characteristics of the ore during the early stages of project planning. These characteristics may influence project design, economics, and the stringency of closure and bonding requirements.

Column rinsing tests to determine cyanide neutralization characteristics can be integrated into the column leach metallurgical testing phase of a project. Prior to disassembling some of the columns to test for tail grade, operators should consider rinsing tests to determine the most effective cyanide destruction method, the length of time required to rinse and neutralize the ore to a required standard, and the costs associated with heap rinsing and cyanide neutralization. Like leaching characteristics, cyanide detoxification characteristics

of leached ores vary considerably depending upon the mineralogy and physical condition of the ore in question.

Struhsacker and Smith (1988) outline the procedures for performing detoxification tests to satisfy regulatory requirements. The leached columns selected for detoxification testing should be representative of the physical and mineralogical conditions of the ore to be leached during operation, and the column leaching procedures employed should be representative of the realistic worst case field conditions (i.e., the longest probable leach cycle and the maximum cyanide loading). The neutralization tests should also be designed so that the number of variables potentially influencing the detoxification results are limited, and the behavior of specific chemical species in the system can thus be properly modeled.

The columns should be rinsed in increments based upon the pore volume (volume of the void space in the ore) in the column. The rinsate from each pore volume should be collected and the relationship of all cyanide species versus pore volume should be established. The rinsing process should be repeated until the residual cyanide concentration curve becomes asymptotic and predictable. This type of column rinse test is applicable in states with effluent standards for cyanide neutralization. A different testing procedure would be necessary in states with residual cyanide neutralization standards.

Based on our experience, (Struhsacker and Smith, 1988), a delayed release of cyanide may occur during the detoxification of fine-grained or porous ores. We believe that this delayed release is driven by both physical flow and chemical diffusion processes influenced by the physico-chemical properties of the spent ore, and is independent of the cyanide destruction method used. The physical flow process is caused by the increased surface area in fine-grained and porous ores, and the resulting tortuous, slow solution flow paths. Larger volumes of rinsing solution and longer rinsing times are thus required to physically reach all of the cyanide-contaminated surfaces and to flush the cyanide out of fine-grained or porous ores.

The chemical diffusion process appears to be driven by a cyanide concentration gradient within the ore particles. In a partially rinsed ore, much of the cyanide has been removed from the exterior surfaces of the ore, but higher concentrations of cyanide remain in the interior of the ore particles. The resulting concentration gradient causes diffusion of cyanide from the interior to the exterior of the ore particles, where it can then be flushed from the system in subsequent rinse cycles. The resulting cyanide degradation curve is characterized by time-delayed peaks of elevated cyanide. Detoxification tests should thus be run well beyond the point where the cyanide degradation curve has flattened out in order to assess the probability of delayed release of cyanide. An example of the delayed release phenomenon is discussed in the following section.

There are special concerns associated with the neutralization of agglomerated ores. Because agglomerated ores are typically fine-grained or clayey, they are subject to the delayed release effect described above. Additionally, the lime added in the agglomeration process acts as a chemical buffer. Consequently, the effluent produced during rinsing of agglomerated ores may meet cyanide detoxification standards, but commonly exceeds specified pH criteria.

AVAILABLE NEUTRALIZATION DATA FOR CYANIDED HEAPS

There are relatively few data in the public domain documenting cyanide neutralization characteristics in either laboratory or field conditions. This is due mainly to the fact that most heap leach projects have been developed in the last decade, many of these are still operating, and few have at this point been neutralized and reclaimed. However, with increasing regulatory scrutiny of cyanide neutralization requirements, some operators and researchers are conducting laboratory and field neutralization tests, and building a database on cyanide neutralization characteristics of leached ore.

As an example of field data on cyanide neutralization, Wharf Resources developed test data on cyanide degradation by fresh water rinsing for their Annie Creek heap leach project in South Dakota. These data are presented in Figure 1 which compare the observed neutralization data versus the theoretical degradation curve for cyanide in a rinsed, spent heap. As shown in Figure 1, cyanide concentrations in this heap were lowered from an initial value of 133 ppm total cyanide to below one ppm in three pore volumes using the fresh water rinsing neutralization method. However, a secondary spike of cyanide measuring more than one ppm total cyanide occurred following the fifth pore volume, and a small cyanide peak occurred after the eighth pore volume. This delayed response is similar to that observed in other leached ores, and is probably due to the physical flow and chemical diffusion processes described above. From an operator's perspective, this delayed release could increase the amount of rinsing required to reach regulatory requirements, and could potentially affect project scheduling and economics. It is interesting to note that the initial heap at the Annie Creek Project was not rinsed and the cyanide was allowed to "self-neutralize". The effluent draining from this heap met regulatory requirements after about seven months.

Test data from column rinse tests for another project in the western United States compare the efficiency of the various chemical treatment methods for cyanide destruction and illustrate the analytical problems associated with free cyanide determinations. Table 1 shows the cyanide neutralization levels and pH values achieved in the first pore volume by fresh water rinsing, acidification using sulfuric acid, and acidification coupled with other chemical treatment methods. The cyanide concentrations in the effluent from this test were determined using the total cyanide, the weak acid dissociable cyanide, and the free cyanide analytical methods.

As revealed in Table 1, acidification to a target pH of 7.5 in the effluent was the most effective method for reducing cyanide levels, with most of the remaining cyanide existing as free or weak acid dissociable cyanide. However, the free cyanide measurements for this case and the fresh water rinse sample are clearly specious because they exceed the total cyanide and weak acid dissociable cyanide values. This is impossible because both total and weak acid dissociable cyanide measurements include free cyanide. Moreover, this discrepancy is not due to random laboratory error; the free cyanide values were determined by independent analyses at three laboratories, all producing essentially the same values. This is strong evidence for analytical interference most likely due to the presence of sulfides and/or thiocyanate (CNS^-) species. The interference effect is particularly acute in the case of the pH 7.5 sample where total cyanide and weak acid dissociable cyanide values are low, and almost 50 mg/l of the free cyanide is due to interference.

The analytical problems associated with free cyanide analyses have significant implications for projects in which the cyanide neutralization compliance criterion is expressed in terms

of free cyanide. Using the pH 7.5 case as an example (Table 1), an operator could be deemed grossly out of compliance if free cyanide were the species designated as the neutralization criterion. However, the same effluent would be deemed much closer to compliance based upon either a total or a weak acid dissociable cyanide neutralization standard.

It should also be noted that the field kits commonly used to measure free cyanide are particularly susceptible to analytical interference problems. Operators relying on field kits for free cyanide analyses should thus be aware of the potential for inaccurate free cyanide measurements.

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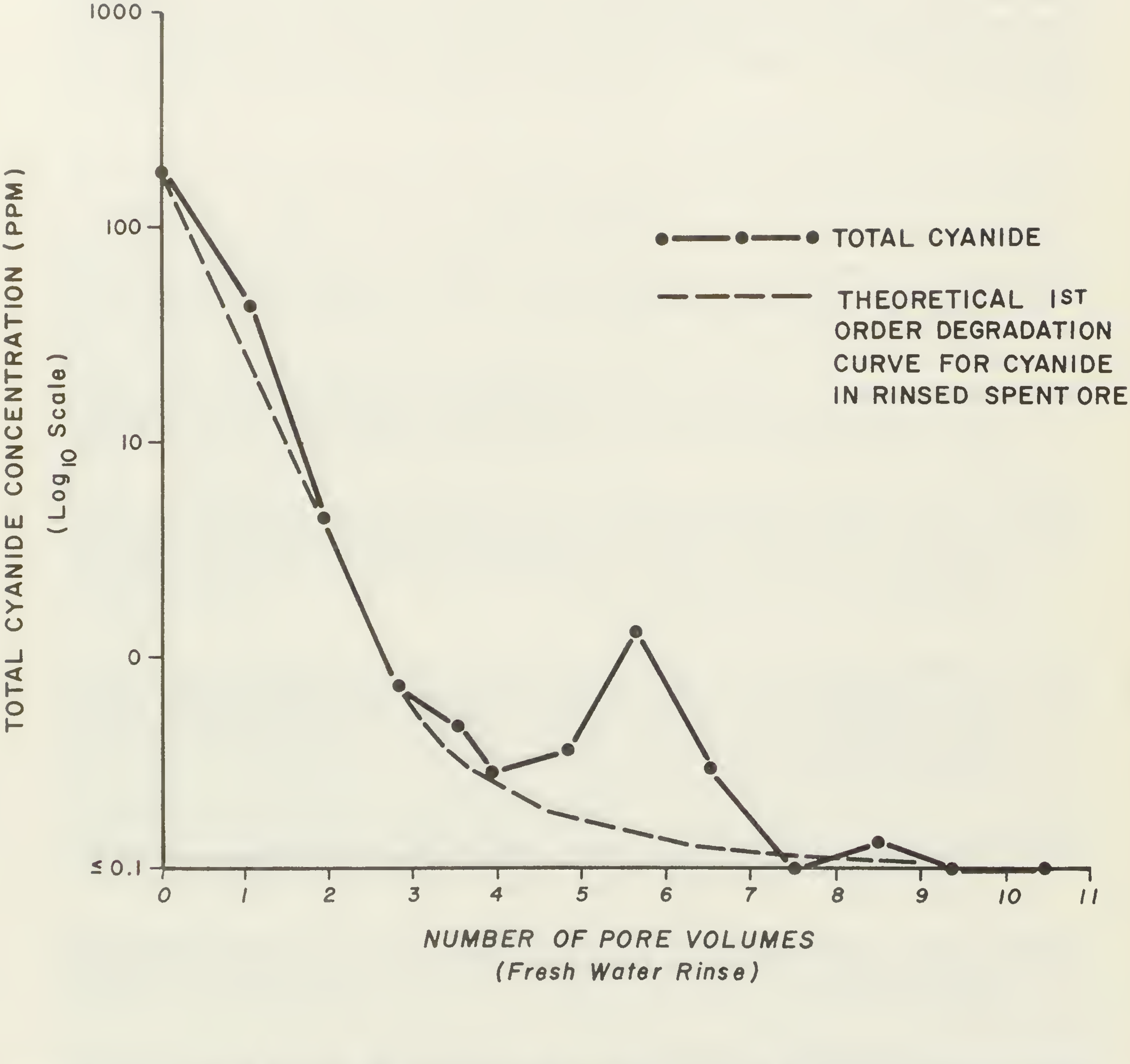

Figure I. *CYANIDE NEUTRALIZATION DATA ILLUSTRATING DELAYED RELEASE OF CYANIDE*

Modified after Smith, 1980

TABLE 1. FIRST PORE VOLUME EFFLUENT pH AND CYANIDE CONCENTRATION

NEUTRALIZATION METHOD	pH ACHIEVED	TOTAL CN	WAD CN	FREE CN[1]
Fresh water rinsing (control)	11.2	110	110	120
Acidification (pH 9)[2]	9.1	77	57	55
Acidification plus peroxide (pH 9)[2]	9.5	72	50	37
Acidification plus ferrous sulfate (pH 9)[2]	8.4	42	28	38
Acidification (pH 7.5)[2]	7.5	4	3.5	55

pH in standard units, all other values in mg/l
1 Weak Acid Dissociable Cyanide
2 Target pH of effluent

EFFECTS OF MINESOIL AMENDMENTS ON REVEGETATION OF BENTONITE MINED LANDS[1/]

D.J. Dollhopf, S.C. Smith and R.B. Rennick[2]

ABSTRACT

The effects of surface manipulation (straw mulch, gouging), chemical amendments (H_2SO_4, $CaCl_2$, gypsum), organic amendments (woodchips, manure), topsoil and irrigation were evaluated from 1980 to 1986 on abandoned bentonite mined lands located near Belle Fourche, SD. Minesoils treated with H_2SO_4 in combination with either gypsum or manure, and minesoils treated with $CaCl_2$ plus gypsum, had SAR and EC significantly reduced from 38 to 8 and 7.0 to 1.8 mmhos/cm, respectively. These treatments had plant production significantly greater (1936 to 3169 kg/ha) compared to the control (416 kg/ha). Application of woodchips and surface gouging had no effect on either minesoil SAR or plant production compared to the control. Applied topsoil (10 cm, SAR 1) quickly became sodic (SAR 27) and had plant production not significantly different compared to the control. The industrial wastes phosphogypsum and $MgCl_2$ brine were evaluated beginning in 1986. After 16 months, $MgCl_2$ and phosphogypsum significantly reduced minesoil SAR (21.3 and 24.5) compared to the control. By the second growing season, mean plant production on $MgCl_2$ treated plots (2717 kg/ha) was greater than on phosphogypsum treated plots (1753 kg/ha).

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INTRODUCTION

The purpose of this research project was to develop reclamation technology for abandoned bentonite mine lands in the Northern Great Plains. The specific objective of this study was to:

- evaluate the effectiveness of sulfuric acid, calcium chloride, gypsum, phosphogypsum, magnesium chloride brine, woodchips, manure, topsoil, surface gouging, straw mulch and emergence irrigation on plant performance and mitigation of adverse physicochemical conditions in minesoils.

MATERIALS AND METHODS

In April 1980, field plots were established 11 km northwest of Belle Fourche, South Dakota on orphan bentonite spoils. Dominant vegetation on adjacent undisturbed lands was composed of big sagebrush and mixed prairie grasses on relatively deep soils, ponderosa pine on rocky hilltops and ridges, and riparian vegetation in localized areas. The climate is semiarid with average annual precipitation of 42 cm. Spoil materials were composed of the Belle Fourche Shale.

Experiment 1

In spring 1980, twelve treatments and a control were implemented at the site in a randomized block design consisting of three replications of each treatment (Table 1). Gypsum was 69 percent $CaSO_4 \cdot 2H_2O$, while the remaining portion was mostly crushed rock. The $CaCl_2$ was 94 percent pure (Type 2). Both gypsum and $CaCl_2$ were applied by hand in a granular form. The H_2SO_4 was applied as 36 N H_2SO_4 (94 percent pure). Application rates for these chemicals were based on the amount of exchangeable sodium present in the soil (Richards 1969). For comparison, chemically equivalent amounts of gypsum + $CaCl_2$ and gypsum + H_2SO_4 were applied to the respective plots. Manure was obtained from a local feedlot and the woodchips came from a nearby sawmill. Once these amendments were applied to the spoil surface, the entire study area was rototilled to a depth of 15 cm. Topsoil, from adjacent native rangeland, was then applied. The vertical mulch treatment consisted of 15 cm wide ditches 1.0 m deep and spaced 1.0 m apart that were filled with manure, and manure was applied to the surface of these plots. Irrigation water was pumped from an abandoned bentonite pit and applied at 0.6 cm day-1 for 20 consecutive days after seeding. The gouger consisted of a wheel equipped tool bar with hydraulically operated plates that formed elongated soil surface

Table 1. Bentonite spoil amendments at Belle Fourche, South Dakota.

	Experimental Treatments[1,2]
1.	No straw mulch
2.	Control
3.	Emergence irrigation
4.	Gouge
5.	Manure (vertical mulch)
6.	Manure @ 224 mt/ha
7.	Manure @ 112 mt/ha + H_2SO_4 @ 20 mt/ha
8.	Woodchips @ 1660m^3/ha
9.	Gypsum @ 6.7 mt/ha + $CaCl_2$ @ 17.2 mt/ha
10.	Gypsum @ 6.7 mt/ha + H_2SO_4 @ 12.3 mt/ha
11.	Gypsum @ 6.7 mt/ha + H_2SO_4 @ 12.3 mt/ha and emergence irrigation
12.	10 cm topsoil
13.	10 cm topsoil and emergence irrigation

[1] All treatments received straw mulch @ 4.5 mt/ha, except Treatment 1.
[2] Metric tons, mt/hectare, ha (.446) = tons/acre
Cubic meters, m^3/hectare, ha (.53) = yd^3/acre

depressions approximately 70 cm long, 30 cm wide, and 10 cm deep. The downslope perimeter of each depression was dammed by a ridge of soil created by the blade. Depressions were spaced approximately 30 cm apart. Except for treatment number one, all treatments were mulched with 4500 kg/ha of straw. Each plot was fertilized with 67 kg/ha N.

All plots were broadcast seeded by hand with a diverse mixture of native and introduced species (Table 2). Following seeding, the study area was subjected to a mulch crimper to anchor the straw and provide a firm seedbed.

Minesoils were analyzed for Cu, Cd, Fe, Pb, Mn, Zn and Ni by DTPA extraction (Lindsay 1971); particle size distribution (hydrometer), NO_3 (phenoldisulfonic acid), B (hot water), Mo (ammonium oxalate), P ($NaHCO_3$), and Se (hot water) according to methods presented by Black (1965); Hg (acid extraction, EPA 1974); SAR, ESP, EC, pH, saturation percentage, Cl, SO_4, HCO_3, CO_3, modulus of rupture, and saturated hydraulic conductivity (method 346) according to methods presented by Richards (1969).

Table 2. Plant species broadcast seeded in Experiments 1 and 2 at the Belle Fourche site.

SPECIES	Experiment 1 (PLS/m^2)	Experiment 2 (PLS/m^2)
Grasses		
Agropyron cristatum (crested wheatgrass, var. Nordan)	4.6	105
A. dasystachyum (thickspike wheatgrass, var. Critana)	12.0	203
A. elongatum (tall wheatgrass)	12.0	60
A. riparium (streambank wheatgrass, var. Sodar)	--	128
A. smithii (western wheatgrass, var. Rosana)	10.0	92
A. trachycaulum (slender wheatgrass, var. Revenue)	7.0	256
Bouteloua curtipendula (sideoats grama)	7.0	267
Sporobolus airoides (alkali sacaton)	0.6	1703
Forbs		
Achillea millifolium (western yarrow)	--	3694
Astragalus cicer (cicer milkvetch)	8.0	228
Helianthus spp. (sunflower)	0.6	--
Kochia prostrata (prostrate kochia)	0.5	--
Linum lewisii (Lewis flax, var. Appar)	1.0	391
Melilotus officinalis (yellow sweetclover)	4.0	137
Petalostemum purpureum (purple prairie clover)	--	825
Ratibida columnaris (prairie coneflower)	5.0	808
Shrubs		
Artemisia cana (silver sagebrush)	--	178
Atriplex canescens (fourwing saltbush)	1.2	34
Atriplex gardneri (gardner saltbush)	1.2	--
A. confertifolia (shadscale)	--	17
A. nuttallii (Nuttall's saltbush)	--	87
Sarcobatus vermiculatus (greasewood)	0.6	--

Infiltration rates were measured on all test plots using an infiltrometer similar to the unit developed by Meeuwig (1971). Clay mineral analysis was performed using the x-ray diffraction technique of Whittig (1965) and semiquantitative analysis (Klages and Hopper 1982) was used to estimate relative proportions of the clay minerals.

Emergent plant density was measured in July 1980 by counting seedlings in 10 systematically located 0.25 m^2 microplots in each plot. Species specific aboveground production was estimated at peak growth in July 1986. Production was estimated by hand-harvesting all vegetation to ground level in 6, 50 x 50 cm microplots per plot.

Experiment 2

In May 1986, field plots were implemented adjacent to those established in 1980 (Experiment 1) to test industrial waste phosphogypsum (40.4 mt/ha) and magnesium chloride brine (36.2 mt/ha). Phosphogypsum was determined to be 82.1% $CaSO_4 \cdot 2H_2O$ and magnesium chloride brine was 40.8% $MgCl_2$. These treatments were replicated three times and plot preparation was identical to Experiment 1 except the seed mix was adjusted (Table 2). Using a modification of the Daubenmire (1959) technique, cover was estimated in 10, 20 x 5 cm microplots, systematically located along a transect in each subplot. Insufficient space in the leveled area prevented new control plots from being implemented. Therefore, values for unamended spoil physicochemical properties were developed using available data from the site. These data include SAR, EC, and saturation percentage values from several data sets obtained over a seven year period.

Total element concentrations in phosphogypsum and magnesium chloride brine were determined by HNO_3 and H_2O_2 digestion (EPA 1987a). In Experiments 1 and 2, analysis of variance was conducted on soil and vegetation data and was tested at the 0.05 probability level. The method of least significant difference was used to separate the means at the 0.05 level (Snedecor and Cochran 1967). Data sets for canopy cover (Table 15) and above plant production (Table 16) had skewed populations. To normalize population distributions for analysis of variance calculations, a logarithmic transformation of Log 10 (x + 1.01) was used (LeClerg et al. 1962).

RESULTS

Pre-Amendment Minesoil Characteristics

Plant growth on these minesoils was limited by the very sodic (SAR 33-38) and clayey (60-68%) nature of these materials (Table 3). These sodic and clayey conditions dominated by smectite mineralogy (Table 4) resulted in a very slow saturated hydraulic conductivity (.003 cm/hr). Surface crusts formed immediately after being wetted and dried. Crust strength was very high (> 5.7 bars) and could prevent seeding emergence or cause plant stem breakage.

The salinity level was moderately high (7.7 mmhos/cm) and trace element levels were not limiting to plant growth (Table 3). The dominant anion was sulfate. The minesoil pH was good (7.6). Nitrate levels were very low and phosphorus levels were moderate.

Table 3. Physicochemical characteristics of two composite minesoil samples used for this investigation located near Belle Fourche, SD.

Sample	Depth (cm)	pH	EC* mmhos/cm	SAR*	ESP*	Water Extract Na	Water Extract Ca	Water Extract Mg	NH_4OAc Extract Na	NH_4OAc Extract Ca	NH_4OAc Extract Mg	CEC*
						meq/L			meq/100g			
1	0-15	7.6	7.7	33.4	46.5	112.0	11.8	10.8	28.0	8.4	10.9	39.6
2	0-15	7.7	7.7	37.3	6.7	102.2	10.2	6.9	13.5	9.3	10.2	37.4

NO_3	P	SO_4	HCO_3	CO_3	Cl	Pb	Ni	Zn	Fe	Mn	Cu	Cd	Hg	Se	Mo	B	Sat. %	Sand	Silt	Clay	Texture
	parts per million																	%			
5.7	15.6	6747	44.8	0.0	95.9	1.6	5.0	8.8	84.8	13.7	6.0	0.40	0.004	0.011	0.34	0.0	86	8.9	31.2	59.9	Clay
3.4	17.4	6203	44.8	0.0	86.0	2.0	5.1	11.0	43.0	25.8	5.6	0.51	0.004	0.009	0.30	0.0	101	2.3	30.0	67.7	Clay

* EC = Electrical Conductivity; SAR = Sodium Adsorption Ratio; ESP = Exchangeable Sodium Percentage; CEC = Cation Exchange Capacity

Table 4. Minesoil modulus of rupture, hydraulic conductivity and clay mineralogy.

Analysis	Composite Minesoil Sample 1
Modulus of Rupture	> 5.7 bars
Saturated Hydraulic Conductivity	0.003 cm/hour
Clay Mineralogy (approximate % of each)	
• Smectite	63
• Illite	17
• Kaolinite	9
• Quartz	11

EXPERIMENT 1

Amendment Effects on Minesoils

Tables 5 through 9 present effects of amendments on minesoil SAR, EC, pH and infiltration rate.

Minesoils treated with H_2SO_4 in combination with either gypsum or manure and minesoils treated with $CaCl_2$ plus gypsum had sodic conditions significantly reduced from a sodium adsorption ratio (SAR) of approximately 38 to 8 during a six year period. These same treatments significantly decreased minesoil electrical conductivity (EC) from approximately 7.0 to 1.8 mmhos/cm. Significant decreases in minesoil SAR were confined to the 0-20 cm depth increment. Significant decreases in EC were present in the 0-10 cm zone. Incorporation of amendments with a chisel plow was limited to approximately the 20 cm depth. Neither manure by itself nor woodchips significantly decreased SAR or EC in minesoils compared to the control. Surface pitting (gouging) had no effect on either SAR or EC. After 10 cm of topsoil (SAR 1) was applied in 1980, it became sodic (SAR 27) by 1986. Sodication of the topsoil was attributed to the upward diffusion of salts from spoils into topsoil. Sprinkler irrigation of these amended minesoils for a 20 day period after seeding had no effect on either SAR or EC.

The mechanism by which H_2SO_4 plus gypsum reduced SAR was unique and not often presented in soil science. No alkaline earth carbonates were present in the minesoil, therefore, H_2SO_4 could not react to produce gypsum. Application of H_2SO_4 did not increase the solubility of native or applied gypsum. Consequently, there was no soluble source of calcium to displace sodium from the cation exchange sites. It was believed that the H_2SO_4 solubilized aluminum and iron from silicate clay minerals. Both Al^{3+} and $Al(OH)^{2+}$ could serve to displace Na^+ from cation exchange sites, and cause a decreased SAR.

Minesoils treated with H_2SO_4 in 1980 (pH 7.1-7.3) were very acidic (pH 4.3-5.4) in 1986 in the 0-10 cm depth. This was believed due to aluminum displacing sodium on the cation exchange sites. Both manure and topsoil treated minesoils had undesirable pH levels (>8.5) to the 10 cm depth. The increased pH was likely due to sodium hydrolysis. Minesoils treated with gypsum plus $CaCl_2$, manure alone and woodchips had a significantly greater infiltration rate (moderately rapid, >6.3 cm/hr) compared to the control (2.8 cm/hr). All other treatments were not significantly different compared to the control or infiltrated significantly less than the control.

Table 5. Mean[1] SAR values compared between years, Belle Fourche, SD[2].

Year	Depth (cm)	Treatment: no straw	control	irrgtn	gouge	manure vertical mulch	manure only	manure $+H_2SO_4$	woodchips	gypsum $+CaCl_2$	gypsum $+H_2SO_4$	gypsum $+H_2SO_4$ irrgtn	topsoil only	topsoil +irrgtn
80	0-5	38.7 A	33.8	33.9	34.8	32.5 A	36.9	34.8 A	38.1	47.7 A	38.4 A	33.5 A	1.0 B	1.0 B
86		31.6 B	38.7	44.1	37.7	28.1 B	20.1	8.8 B	34.3	9.2 B	7.3 B	10.1 B	26.3 A	28.0 A
80	5-10	38.7	33.8	33.9	34.8	32.5	36.9	34.8 A	38.1	47.7	38.4 A	33.5 A	1.0 B	1.0 B
86		32.2	33.4	35.0	37.2	33.7	26.2	14.9 B	38.7	10.2	16.4 B	16.2 B	27.2 A	32.9 A
80	10-20	38.7	33.8	33.9	34.8	32.5	36.9	34.8 A	38.1	47.7	38.4 A	33.5 A	35.8	35.8
86		32.4	35.0	28.2	30.9	34.9	32.5	20.8 B	33.9	18.7	19.0 B	16.9 B	29.0	36.2
80	20-38	38.7	33.8	33.9	34.8	32.5	36.9	34.8	38.1	47.7	38.4	33.5	35.8	35.8
86		30.1	35.0	28.6	28.2	30.8	31.7	27.7	31.6	26.6	26.1	27.8	33.8	35.6

1 Mean of three replications.
2 Statistically significant comparisons are identified by boxes. Mean values are significantly ($P \leq .05$) different if followed by a different letter.

Table 6. Mean[1] 1986 SAR values, Belle Fourche, SD[2].

Depth (cm)	no straw	control	irrgtn	gouge	manure vertical mulch	manure only	manure $+H_2SO_4$	woodchips	gypsum $+CaCl_2$	gypsum $+H_2SO_4$	gypsum $+H_2SO_4$ +irrgtn	topsoil only	topsoil +irrgtn
	Treatment												
0-5	31.6	38.6	44.1 a	37.7	28.1	20.1 b	8.7 d	34.3	9.2 b	7.33 b	10.0 b	26.3 b	27.9
	BC	AB	A	ABC	BCD	D	E	ABC	E	E	E	DC	BCD
5-10	32.1	33.3	35.0 ab	37.1	33.6	26.2 ab	14.8 c	38.7	10.1 b	16.4 ab	16.1 b	27.2 ab	32.8
	A	A	A	A	A	AB	BC	A	C	BC	BC	AB	A
10-20	32.3	34.9	28.2 b	30.8	34.9	32.5 a	20.7 bc	33.9	18.6 a	19.0 ab	16.9 b	29.0 ab	36.2
	AB	A	ABC	ABC	A	AB	ABC	AB	BC	BC	C	ABC	A
20-38	30.1	35.0	28.6 b	28.1	30.8	31.7 a	27.7 ab	31.5	26.6 a	26.1 a	27.8 a	33.8 a	35.5
38-76	28.9	32.7	36.5 ab	30.4	33.8	35.0 a	33.7 a	29.7	27.5 a	29.2 a	32.3 a	28.7 ab	30.6
76-152	24.8	30.8	30.7 b	23.7	32.0	34.0 a	26.9 ab	27.8	27.5 a	27.9 a	27.9 a	24.0 b	37.3

1 Mean of three replications.
2 Statistically significant comparisons are identified by boxes. Upper case letters (horizontal boxes) show treatment comparisons. Lower case letters (vertical boxes) show depth comparisons. Mean values are significantly ($P \leq .05$) different if associated with a different letter.

Table 7. Mean[1] EC (mmhos/cm) values compared between years, Belle Fourche, SD[2].

Year	Depth (cm)	no straw	control	irrgtn	gouge	manure vertical mulch	manure only	manure $+H_2SO_4$	woodchips	gypsum $+CaCl_2$	gypsum $+H_2SO_4$	gypsum $+H_2SO_4$ irrgtn	topsoil only	topsoil +irrgtn
80	0-5	6.89	7.53	8.38	7.46	6.65	7.47	6.96 A	7.81	7.22 A	6.88 A	7.20 A	1.00 B	1.00 B
86		8.98	6.55	8.89	7.18	8.28	3.03	2.68 B	3.22	1.56 B	1.63 B	1.31 B	3.88 A	4.00 A
80	5-10	6.89	7.53	8.38	7.46	6.65 B	7.47	6.96	7.81	7.22	6.88 A	7.20	1.00 B	1.00 B
86		9.96	8.24	10.80	10.21	11.52 A	3.15	3.33	3.26	3.55	2.83 B	2.79	7.02 A	6.45 A
80	10-20	6.89	7.53	8.38	7.46	6.65	7.47	6.96	7.81	7.22	6.88	7.20	6.07	7.25
86		8.30	9.32	10.33	10.05	10.48	4.19	4.68	7.19	7.79	5.90	5.83	8.21	10.84
80	20-38	6.89	7.53	8.38	7.46 B	6.65	7.47	6.96	7.81	7.22	6.88	7.20	6.07 B	7.25
86		10.33	13.93	10.06	10.69 A	11.18	9.05	8.54	8.65	8.20	10.15	11.14	14.36 A	10.84

1 Mean of three replications.
2 Statistically significant comparisons are identified by boxes. Mean values are significantly ($P \leq .05$) different if followed by a different letter.

Table 8. Mean[1] pH values compared between years, Belle Fourche, SD[2].

		Treatment												
Year	Depth (cm)	no straw	control	irrgtn	gouge	manure vertical mulch	manure only	manure $+H_2SO_4$	woodchips	gypsum $+CaCl_2$	gypsum $+H_2SO_4$	gypsum $+H_2SO_4$ irrgtn	topsoil only	topsoil +irrgtn
80	0-5	6.9	7.4	7.8	7.5	7.8	7.2 B	7.3	7.4	6.9 B	7.1	7.1 A	7.3 B	7.3
86		7.2	8.0	8.0	7.7	8.2	8.9 A	5.4	7.8	7.9 A	4.9	4.4 B	8.8 A	8.6
80	5-10	6.9	7.4	7.8	7.5	7.8	7.2 B	7.3 A	7.4	6.9	7.1 A	7.1 A	7.3	7.3 B
86		6.9	7.5	7.7	7.3	8.0	8.8 A	4.4 B	7.6	7.4	4.9 B	4.3 B	7.7	8.3 A
80	10-20	6.9	7.4	7.8	7.5	7.8	7.2	7.3	7.4	6.9	7.1	7.1	7.4	7.6
86		7.5	7.3	7.1	7.2	7.9	7.8	5.7	7.3	7.3	6.7	5.9	7.2	8.1
80	20-38	6.9	7.4	7.8	7.5	7.8	7.2	7.3	7.4	6.9	7.1	7.1	7.4	7.6
86		7.4	7.5	7.6	7.7	7.5	7.5	7.0	7.4	7.5	7.0	6.9	7.5	7.9

1 Mean of three replications.
2 Statistically significant comparisons are identified by boxes. Mean values are significantly ($P \leq .05$) different if followed by a different letter.

Table 9. Simulated rainfall infiltration rate after 30 minutes in bentonite minesoils, 1986.

Treatment*	Infiltration Rate, cm/hr Mean+
No straw mulch	0.5 a
Control	2.8 ab
Emergence irrigation	1.2 ab
Gouge	1.1 ab
Vertical mulch	4.2 bc
Manure	11.3 e
Manure + H_2SO_4	1.9 ab
Woodchips	8.5 de
Gypsum + $CaCl_2$	10.2 e
Gypsum + H_2SO_4	6.8 cd
Gypsum + H_2SO_4 + emergence irrigation	4.1 bc
Topsoil	3.2 ab
Topsoil + emergence irrigation	1.4 ab

+ Means followed by the same letter are not significantly different at the 95% level of confidence.

Amendment Effects on Vegetation Development

Three months after seeding in spring 1980, plant density was notably greater in woodchip and topsoil treated minesoils. Minesoils treated with gypsum, H_2SO_4, and $CaCl_2$ had little or no plant growth (Table 10). These results indicated that chemical amendments will not provide a suitable plant establishment environment three months after seeding. This meant that chemical amelioration of the sodic problem was not immediate. Surface pitting (gouging) and manure application did not enhance plant density compared to the control three months after seeding. Emergence irrigation did not enhance plant density compared to the control. Emergence irrigation in combination with H_2SO_4 and gypsum did not improve plant density compared to the same chemical application alone. When these sodic minesoils were topsoiled, emergence irrigation increased plant density by 40% the first growing season. This indicates emergence irrigation has merit when the root zone has no physical or chemical limitations. Without topsoil, emergence irrigation did not enhance first year plant density.

Table 10. Plant density by treatment and life form, July 1980, Belle Fourche, South Dakota.

Treatment	Density (plants/m^2)				
	Grasses	Forbs	Legumes	Shrubs	Total
No straw mulch	0	0	0	0	0
Control	33	58	0	0	91
Emergence irrigation	92	3	0	0	95
Gouge	25	16	0	0	41
Manure vertical mulch	0	33	0	0	33
Manure, 224 Mg/ha	33	58	0	0	91
Manure, 112 Mg/ha + H_2SO_4	0	0	0	0	0
Woodchips	150	100	16	0	266
Gypsum + $CaCl_2$	8	8	0	0	16
Gypsum + H_2SO_4	0	16	0	0	16
Gypsum + H_2SO_4 + emergence irrigation	0	0	0	0	0
Topsoiled	167	83	0	0	250
Topsoiled + emergence irrigation	167	183	16	0	350

After seven growing seasons, the manure treatments (i.e. vertical mulch, surface applied, H_2SO_4 combination) and gypsum in combination with either H_2SO_4 or $CaCl_2$ had plant production significantly greater (1936 to 3169 kg/ha) compared to the control (416 kg/ha). There was no difference between manure tilled into the minesoil surface (30 cm) or placed in trenches to the 90 cm depth (Figure 1).

Minesoils treated with either woodchips or topsoil had plant productivity that was not significantly different compared to the control. Mean plant production on woodchip treated plots was less than on plots treated with combinations of H_2SO_4, $CaCl_2$, gypsum and manure, but these differences were not significant except for the H_2SO_4 plus manure treatment.

Surface pitting (gouging) had no effect on plant performance compared to the control into the seventh growth season. Although a straw mulch crimped into the minesoil surface helped increase first year plant density, there was no significant difference between mulch or no mulch after seven growing seasons.

"Rosana" western wheatgrass was the most successfully seeded species, followed by tall and slender wheatgrass. Seeded species comprised 65% of the canopy coverage, but invading species were commonly encountered. Although applications of H_2SO_4 decreased minesoil pH to low levels (4.3-5.4), this decrease had no effect on plant performance. Similarly, increased pH levels (8.3-8.9) that resulted from manure application and topsoil sodication had no effect on plant performance.

* Total production values are significantly ($P \leq .05$) different if capped by a different letter.

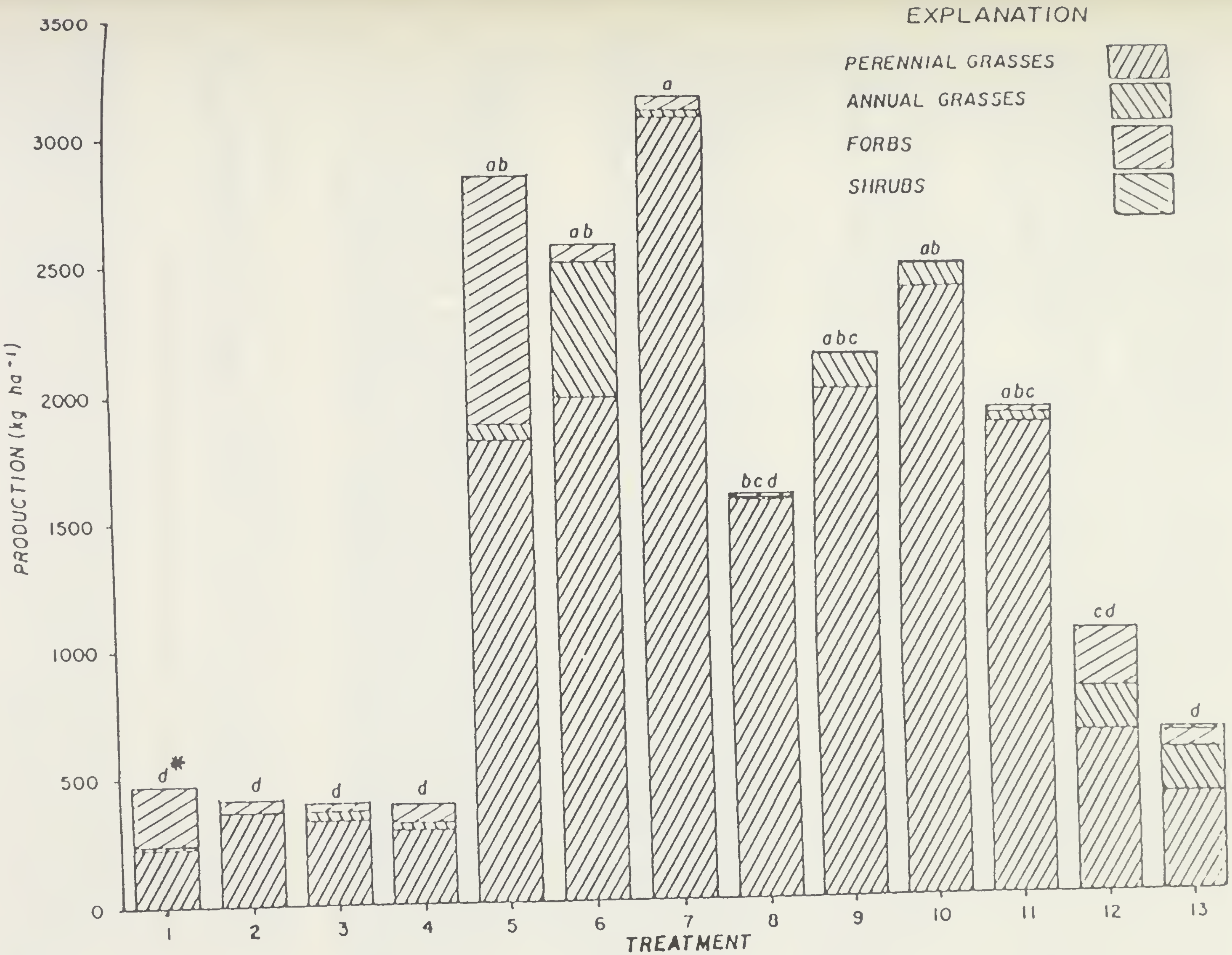

Figure 1. Aboveground production by plant class and treatment, June 1986, Belle Fourche, S.D.

Treatments: 1 = no straw mulch, 2 = control, 3 = irrigation, 4 = gouge, 5 = vertical mulch, 6 = manure, 7 = manure + H_2SO_4, 8 = woodchips, 9 = gypsum + $CaCl_2$, 10 = gypsum + H_2SO_4, 11 = gypsum + H_2SO_4 + irrigation, 12 = topsoil, 13 = topsoil + irrigation.

EXPERIMENT 2

Phosphogypsum and Magnesium Chloride Brine Characteristics

Phosphogypsum is a by-product of the phosphate fertilizer industry. Phosphate ore containing calcium is processed with sulfuric acid (H_2SO_4). Gypsum ($CaSO_4 \cdot 2H_2O$) is precipitated as a silt sized (.002-.05mm) waste product. Phosphogypsum consists of the tailings material (80-99% $CaSO_4 \cdot 2H_2O$), mineral impurities, and less than 1% phosphate (P_2O_5) (Keren and Shainberg 1981). Thousands of tons are produced annually in the United States with no apparent market. The phosphogypsum used in this investigation was supplied by J.R. Simplot Company, Pocatello, Idaho.

Magnesium chloride brine is produced as a by-product at table salt ($NaCl_2$) evaporation facilities. The brine consists of 35 to 45% $MgCl_2$, with minimal amounts of calcium, sodium, potassium, nitrate, and sulfate occurring as impurities.

In the phosphogypsum amendment, total silver concentration was 15% greater than the suspected phytotoxic level (Table 11). Total cadmium and selenium concentrations were enriched above expected background levels in soil. Total concentrations of the other analyzed trace elements were within the normal range for soils. No enrichment of trace elements was detected in the magnesium chloride brine.

Assuming that 0.4 hectares - 30.5 cm of spoil weighs approximately 1792 metric tons, incorporation (35 cm) of the phosphogypsum amendment results in dilution of 40.4 mt (field rate) into 4480 mt of spoil with 1 hectare. This represents a dilution ratio of approximately 110:1. Although several trace elements were enriched in the phosphogypsum, amendment dilution by incorporation clearly minimizes the potential for plant growth problems.

Radium 226 occurs in much of the phosphate ore from the Western United States. Phosphogypsum tailings produced in Idaho and Utah are reported to have concentrations of radium 226 exceeding the U.S. EPA suspect level of 5 picocuries/gram (Range Inventory and Analysis 1986).

In a Wyoming study, 30 cm incorporation of phosphogypsum amendment (35.5 mt/ha) with an average of 26 picocuries/gram radium 226, resulted in no significant increase in radium 226 levels compared to background levels (Range Inventory and Analysis 1986).

Table 11. Trace element total concentrations[1] in phosphogypsum and magnesium chloride brine amendments.

Element	Background Level-Source[2]		Phytotoxic Level-Source		Phospho-Gypsum	Magnesium Chloride
Silver	.03-.09	g	2	b	2.3	.36
Aluminum	57,000	i	---		1380.0	.2
Arsenic	3.6-8.8	d	100	a	1.5	1.4
Barium	265-835	c	---		73.0	<1.0
Beryllium	1.6	c	10	f	<.5	.22
Cadmium	.07-1.1	c	100	a	10.0	.95
Cobalt	8.2	c	50	f	<1.0	.01
Chromium	20-85	d	100	f	34.0	.08
Copper	10-50	b	100	b	9.5	.3
Iron	27,500	c	---		330.0	28.8
Mercury	.04-.28	d	5	b	<.1	.004
Manganese	260-840	d	3000	e	3.3	1.32
Nickel	19	c	100	f	6.6	.08
Lead	17-26	d	1000	a	4.4	.06
Antimony	.9	c	10	f	<1.0	<1.0
Selenium	.2-.5	d	10	b	5.0	<.005
Tin	.6-1.7	d	50	f	<10.0	---
Thallium	.02-2.8	h	10	b	<1.0	.1
Vanadium	58	d	100	f	27.0	3.9
Zinc	34-83.5	d	500	a	37.0	4.0

[1] Concentrations are given in ppm on a dry weight basis.

[2] Source a is EPA (1987a); Source b is EPA (1987b); Source c is Kabata-Pendias and Pendias (1984); Source d is Shacklette and Boerngen (1984); Source e is Kovalskiy (1974); Source f is Kabata-Pendias (1979); Source g is Smith and Carson (1977a); Source h is Smith and Carson (1977b); and Source i is Tidball and Severson (1975).

Amendment Effects on Minesoils

The effects of these amendments on site reclamation was evaluated for only 16 months and results must be considered preliminary. Representative unamended spoil SAR and EC across the research site were determined to be 33.8 and 8.0 mmhos/cm, respectively. The representative value for unamended spoil saturation percentage was 127. The preceding mean values were developed using data sets from 1980 pre-amendment sampling, 1986 sampling of the 1980 control plot, and pre-amendment sampling for this study.

Results are presented in Tables 12, 13 and Figure 2. Application of phosphogypsum and $MgCl_2$ significantly reduced minesoil (0-5 cm) SAR from 33.8 to 24.5 and 21.3, respectively, during a 16 month period. During the first year, minesoil (0-5 cm) mean EC (8.0 mmhos/cm) increased notably with application of phosphogypsum (10.1 mmhos/cm) and $MgCl_2$ (15.9 mmhos/cm). The EC is expected to eventually decrease well below 8.0 mmhos/cm as the SAR decreases to a low level, and leaching is enhanced as a result of increased infiltration rate. Following 30 minutes of simulated rainfall, minesoil infiltration rates were 2.8 cm/hr on phosphogypsum treated minesoils and 3.8 cm/hr on $MgCl_2$ treated minesoils, compared to 0.1 cm/hr on unamended spoil.

Amendment Effects on Vegetation Development

Total seedling density was not significantly different between phosphogypsum and magnesium chloride treatments, although grass, forb and shrub densities were different for each treatment (Table 14).

Plant density into the first growing season for these two treatments was 191.8 plants/m^2, when fertilized with 67 kg/ha nitrogen. Higher and lower rates of nitrogen decreased plant density. Although these plant densities are less than those measured in 1980 on topsoil and woodchip treated minesoils, they are notably greater than densities measured on manure, $CaCl_2$, gypsum and H_2SO_4 treated minesoils.

Table 12. Minesoil SAR values[1] at the Belle Fourche site.

		SAR			
YEAR	TREATMENT	0-5 cm	5-10 cm	10-20 cm	20-35 cm
1986	Phosphogypsum	30.7 b[2]	31.6 a	28.4 a	29.3 a
	$MgCl_2$ brine	20.4 a	32.0 a	33.8 a	35.2 a
	Spoil	33.8 b	33.8 a	33.8 a	33.8 a
1987	Phosphogypsum	24.5 a	29.3 a	28.4 ab	27.8 a
	$MgCl_2$ brine	21.3 a	26.3 a	26.3 a	31.7 a
	Spoil	33.8 b	33.8 a	33.8 b	33.8 a

1 - Values from treated plots represent the mean of 3 replications. Spoil values represent the overall mean from 3 data sets.

2 - Means followed by the same letter in the same column indicate no significant difference (P=0.05).

Table 13. Minesoil electrical conductivity (EC) values[1] at the Belle Fourche site.

YEAR	TREATMENT	EC (mmhos/cm) 0-5 cm	5-10 cm	10-20 cm	20-35 cm
1986	Phosphogypsum	11.1 ab[2]	10.9 a	9.5 ab	8.9 a
	$MgCl_2$ brine	17.0 b	19.1 b	12.4 b	7.6 a
	Spoil	8.0 a	8.0 a	8.0 a	8.0 a
1987	Phosphogypsum	10.1 ab	11.6 ab	11.6 b	10.0 ab
	$MgCl_2$ brine	15.9 b	14.0 b	12.8 b	12.9 b
	Spoil	8.0 a	8.0 a	8.0 a	8.0 a

[1] - Values from treated plots represent the mean of 3 replications. Spoil values represent the overall mean from 3 data sets.

[2] - Means followed by the same letter in the same column indicate no significant difference (P=0.05).

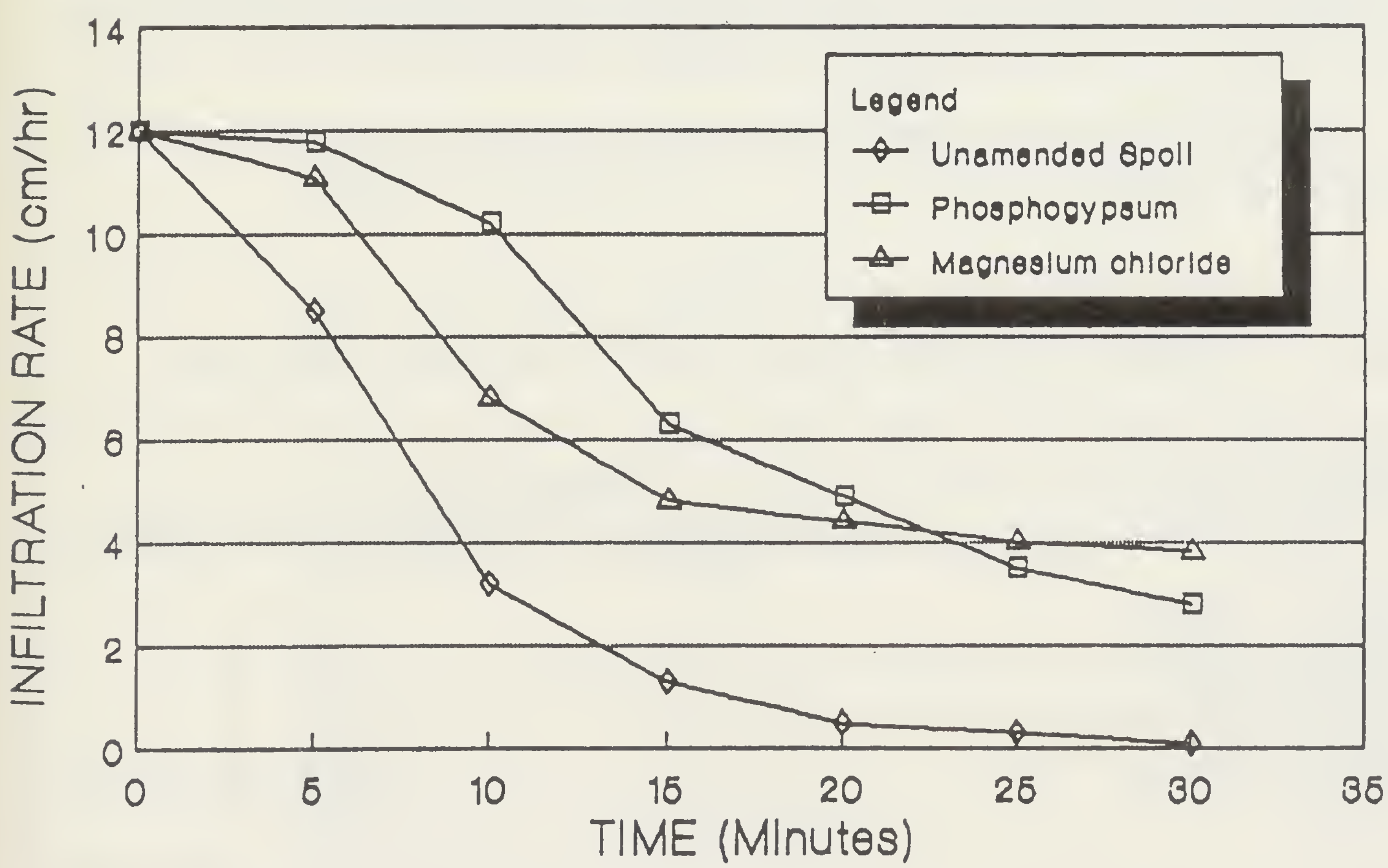

Figure 2. Minesoil infiltration rates over time at the Belle Fourche site.

Table 14. Seedling density[1] (plants/m^2) in 1986, by chemical amendment at the Belle Fourche site.

TREATMENT	SEEDED GRASS	ANNUAL GRASS	SEEDED FORB	SEEDED SHRUB	TOTAL
Phosphogypsum	47.3 b[2]	75.3 a	19.0 b	1.5 b	143.2 a
Magnesium chloride	93.1 a	8.2 b	36.5 a	3.1 a	139.0 a

[1] - N = 3.

[2] - Means followed by the same letter in the same column indicate no significant difference (P=0.05).

Plant canopy cover of 39% on $MgCl_2$ treated minesoils was significantly greater than 28% on phosphogypsum treated minesoils (Table 15).

Above ground plant production was 1753 kg/ha on phosphogypsum treated plots and 2717 kg/ha on $MgCl_2$ treated plots (Table 16). Production of pioneering (non-seeded) annual forbs comprised 60% of total production on phosphogypsum treated plots and 83% on $MgCl_2$ treated plots.

Based on these data, $MgCl_2$ performed better than phosphogypsum after two growing seasons.

Table 15. Summer, 1987 percent canopy cover[1] at the Belle Fourche site.

PLANT CLASS	TREATMENT	
	Phosphogypsum	Magnesium chloride
Seeded Grass	7.5 a[2]	6.4 a
Annual Grass	2.6 a	3.0 a
Seeded Forb	0.9 a	2.4 a
Non-Seeded Forb	15.2 b	26.7 a
Seeded Shrub	2.5 a	0.8 a
Total	28.6 b	39.3 a

[1] - N = 3.

[2] - Means followed by the same letter in the same row indicate no significant difference (P=0.05).

Table 16. Summer, 1987 plant production[1] (kg/ha) at the Belle Fourche site.

PLANT CLASS	TREATMENT			
	Phosphogypsum		Magnesium chloride	
Seeded Grass	326.8	a[2]	230.8	a
Annual Grass	286.4	a	63.6	b
Seeded Forb	35.5	a	7.6	a
Non-seeded Forb	1058.4	b	2271.2	a
Seeded Shrub	46.0	a	144.0	a
Total	1753.1	a	2717.2	a

1 - N = 3.

2 - Means followed by the same letter in the same row indicate no significant difference (P=0.05).

CONCLUSIONS

Longterm reclamation of abandoned bentonite minesoils that are sodic should be accomplished with the aid of chemical amendments. Only in this manner can the sodic problem be mitigated permanently.

- Gypsum in combination with either H_2SO_4 and $CaCl_2$ were the best chemical amendments.

- H_2SO_4 has a much lower cost compared to $CaCl_2$ which makes it the amendment of choice in combination with gypsum.

- Although H_2SO_4 was not tested alone, these results indicate that calcium from gypsum did little to improve the minesoil chemistry. Therefore, H_2SO_4 alone may be sufficient to reduce the sodic condition of these minesoils.

- If $CaCl_2$ is selected, half of the amendment field requirement can be composed of gypsum or phosphogypsum which are much less costly.

- Both gypsum and phosphogypsum should not be applied alone to remediate a sodic problem, since their solubility may be too low to be effective during the early years of reclamation.

- $MgCl_2$ may be the amendment of the future with the best cost:benefit ratio. However, after only 16 months of field study, results are too preliminary to make an accurate recommendation.

- The calculated amendment field application rate must include factors for purity, proportion greater than 60 mesh, and be increased 25% to account for the lack of quantitative displacement.

On near level postmine landscapes, application of only chemical amendments may be adequate for successful reclamation. However, since chemical amendments may not remediate the sodic problem immediately, sloped areas should be stabilized with both pitting (ditcher-diker or gouging) and woodchips, manure or topsoil. These treatments will help control erosion and enhance first year plant density.

Less than 30 cm of topsoil should not be placed over sodic bentonite mine spoils since it may rapidly sodicate resulting in a permanent loss in land capability. The 10 cm of topsoil applied in this study quickly became sodic. Merrill et al. (1980) indicated sodication by upward sodium diffusion would be largely confined to the 15-20 cm topsoil zone immediately above the sodic spoil. If this is the case, then 30 cm or more of topsoil will provide a zone near to the surface that will not sodicate in the future, and the land capability for plant growth may not be reduced.

- If less than 30 cm of topsoil is used, it should be in combination with chemical amendments to prevent topsoil sodication.

Manure applications provided excellent plant performance, but availability and cost feasibility at rates as high as 224 mt/ha (100 T/A) are unknown.

Land reclamationists in the Northern Great Plains have neither the experience nor the equipment to apply concentrated H_2SO_4 on minesoils on a large scale. Existing experience from other parts of the United States needs to be mobilized rapidly into our region, otherwise site project plans will quickly conclude application of H_2SO_4 is not feasible. One company in the southwest United States applies H_2SO_4 to 6,000 ha of land annually.

The $MgCl_2$ brine has great potential as a low cost effective amendment. Only with continued monitoring will the merits of this amendment be determined.

Readers seeking information about chemical amendment costs are referred to Dollhopf et al (1988). In that report, amendment costs, purity, particle size distribution and physical nature (i.e. liquid or solid) are compared from numerous suppliers.

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BONDING AND LONG-TERM LIABILITY FOR HARDROCK MINING IN WISCONSIN

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ABSTRACT

Public concern that followed the discovery of massive-sulfide ore bodies in northern Wisconsin in the 1960s and 1970s prompted legislative initiatives that culminated in the Metallic Mining Reclamation Act (MMRA) and provisions for long-term liability. MMRA was revised, effective June 1978, after much debate and discussion by the mining industry, the public, environmental groups, and the Public Intervenor over the inadequacies of the initial 1973 version. MMRA is a broad statute that controls the reclamation of metallic mining sites, and addresses issues attendant to hardrock mining ranging from the requirements for the collection of premining baseline environmental data through procedures for completion of reclamation and bond release requirements. The long-term liability initiative was one of many recommendations made by the Governor's Economic Development Coordinating Committee (EDCC) during the mid to late 1970s. Long-term liability addresses personal or property injuries resulting from mining. The EDCC study found that persons harmed by mining operations in Wisconsin would find it difficult to recover damages under existing law. Chapter 353, Laws of 1979, created a mining damage claim fund which allows injured parties to recover damages for mining-related injuries through a no-fault process up to a maximum of $150,000 per claim to a person or property based on finding of strict liability.

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INTRODUCTION AND BACKGROUND

The period of the late 1960s and early 1970s was the dawning of environmental awareness both in the nation and in Wisconsin. The National and the State Environmental Policy Acts had only recently been enacted into law and coincidental with this activity was Kennecott Copper Corporation's discovery of the Flambeau copper/gold deposit, a massive-sulfide ore body located in northern Wisconsin. In the late 1960s, the Natural Resources Council of State Agencies appointed a subcommittee on Surface Mining to investigate problems related to mining; the 1971 Wisconsin Senate Bill 525 was a direct result. As originally conceived and introduced by Senator Clifford Krueger, S.B. 525 was aimed at regulating surface and underground mining, metallic as well as nonmetallic mining, and contained provisions for reclamation, zoning of mineral reservation districts, and authorization for the Wisconsin Department of Natural Resources (WDNR) to restore orphaned mined lands (Braden, 1977). The final bill (S.B. 39) which passed the legislature as Ch. 318, Laws of 1973, the Metallic Mining Reclamation Act (MMRA), ss. 144.80 to 144.94 Wis. Stats., was clearly a compromise and was widely criticized.

Public Participation

The laws governing metallic mining and reclamation were not considered comprehensive enough to deal with the new generation of massive-sulfide ore bodies. Detractors of this first version of MMRA summarized its shortcomings as follows: was too narrow in scope; nonmetallic minerals were excluded; provisions for zoning mineral reservation districts were omitted; provisions for reclaiming orphaned mined lands were omitted; inadequate permitting standards were defined; ambiguous hearing procedures were defined; the provisions of WEPA were not sufficiently integrated; contained loopholes for exploration activities; provided an inadequate fee structure; offered insufficient opportunities for public participation; contained inadequate provisions for bonding; allowed excessive time intervals for project evaluation; favored design standards to the exclusion of performance standards; provided excessive discretion for enforcement; and the definition of abandonment was excessively vague (Peshek, 1981 and Russell, 1981).

The Economic Development Coordinating Committee (EDCC), organized by the Governor's Office to help develop mining policy, reported on the state's potential for mining development. They projected 10 new mines in northern Wisconsin over the next 20-30 years and 10 new mines in the southwestern part of the state during the same time period (Milbourne, 1976). By the fall of 1976, the EDCC had initiated over a dozen topical multiagency study groups. As the 1977 legislative session approached, Wisconsin's new mining policy began to crystallize. The Wisconsin Legislature approached mineral policy by engaging interest groups like

the mining industry, environmentalists, local townspeople, Public Intervenor, and Indian tribes in the consensus process, a process that has dominated Wisconsin's mining policy decisions.

During the 1977-1978 legislative session MMRA was extensively revised (Chapter 421, Laws of 1977, effective June 1978). Chapter 421 required new administrative rules for metallic mineral exploration, prospecting, and mining. Though the quality and workability of this legal structure remains untested on a newly developed mine, it is thought to be an improvement over Chapter 318, Laws of 1973. The revised metallic mining rule, ch. NR 132, Wis. Adm. Code, became effective in September 1982.

The permitting process for a new metallic mining operation now provides ample opportunity for public participation through requirements for informational meetings, hearings, and written comment periods. Additionally, in accordance with s. 144.838, Wis. Stats., *(1) A county, town, village, city or tribal government likely to be substantially affected by potential or proposed mining may designate an existing committee, or establish a committee, for purposes of:... (c) Reviewing and commenting on reclamation plans... (5) Such counties, towns, villages or cities may participate as a party in the hearing on the application and may make recommendations on the reclamation plan and future use of the project site.* Further, the Wisconsin legislature passed Act 399 in 1987 which authorized local units of government to negotiate an agreement with a mining operator and includes among other things restrictions on land use. Negotiated local agreements can either affirm local input in the process or functionally remove local input because the attendant financial enticements have a tendency to sway the local decision making.

Public sentiment can be manipulated to support an outright moratorium on mining or to severely restrict mining by insistence on prohibitive conditions in the mining permit. The siting of a mine, a highly controversial activity in Wisconsin, creates a quandary similar to the siting of landfills and sewage treatment facilities. Mining is usually permitted as a conditional land use, but local zoning strongly influences mineral policy development. Pursuant to s. 144.85(5)f, Wis. Stats., a mining permit can be issued only if the proposed mining operation conforms with all applicable zoning ordinances. Zoning is used to control mining operations by placing restrictions on hours of operation, blasting procedures, truck traffic, reclamation, aesthetics, and hiring practices to name a few. But, zoning can be used as a legal tool to ban mining outright, or at the very least mismanage the mineral resources in the state. A portion of the public will always express opposition to the idea of a mining project.

BONDING

Given that a mining project attains local zoning approval and upon notification that an application for a mining permit has been approved by the department but prior to commencing mining, pursuant to s. 144.86, Wis. Stats., *the operator shall file with the department a bond*

conditioned on faithful performance of all the requirements of the MMRA and all rules adopted under the MMRA. The amount of the bond or other security required shall be equal to the estimated cost to the state of fulfilling the reclamation plan, in relation to that portion of the site that will be disturbed by the end of the following year. The estimated cost of reclamation of each mining site shall be determined by the department on the basis of relevant factors including, but not limited to, expected changes in the price index, topography of the site, methods being employed, depth and composition of the overburden and depth of the mineral deposit being mined. Upon approval of the operator's bond, mining application and certificate of insurance, the department shall issue written authorization to commence mining at the permitted mining site in accordance with the approved mining and reclamation plans.

Additionally, in accordance with s. 144.85(4)a, Wis. Stats., *the department shall require an applicant to furnish, as part of the mining permit application, an itemized statement showing the applicant's estimation of the cost to the state of reclamation. The department may, at the applicant's expense, contract with an independent person to estimate the cost to the state of reclamation if it has reason to believe that the applicant's estimated cost of reclamation may not be accurate.*

Further, in accordance with s. 144.87(f), Wis. Stats., *if the applicant submits an application to cancel any or all of the unmined part of the mining site, the department shall ascertain, by inspection, if mining has occurred on the land. No land where mining has occurred may be removed from a permitted mining site or released from bond or security under this subsection, unless reclamation has been completed to the satisfaction of the department.*

Certificate of Completion of Reclamation and Bond Release

MMRA requires a notice of completion of reclamation (NOC) initiated by the operator. The NOC indicates that work required in the reclamation plan is completed and that all criteria have been fulfilled. The WDNR issues the Certificate of Completion (COC), reduces the bond proportionate to the work completed, and issues a statement to that effect after a hearing, if and only if more than 4 years have passed since the NOC. Twenty years after the COC, the WDNR is authorized to release the remaining portion of the bond provided the site meets the requirements of the reclamation and long-term management plans.

Pursuant to s. 144.90(1), Wis. Stats., *upon the petition of the operator, but not less than 4 years after notification to the department by the operator of the completion of the reclamation plan, if the department finds after conducting a hearing that the operator has completed reclamation for any portion of the mining site in accordance with the reclamation plan, the department shall issue a certificate of completion setting forth a description of the area reclaimed and a statement that the operator has fulfilled its duties under the reclamation plan as to that area. (2) Upon the issuance of any*

certificate of completion for any portion of the mining site, but not for the entire mining site, the department shall allow the operator to reduce the amount of the bond to an amount which shall equal the estimated cost of reclamation of the portion of the mining site which is disturbed or for which reclamation has been completed but no certificate of completion has been issued... (4) After 20 years after the issuance of a certificate of completion for the entire mining site, the department shall release the bond if the department finds that the reclamation plan has been complied with. MMRA does not provide for phased operational releases as does the Surface Mining Control and Reclamation Act (SMCRA).

Closure and Long-term Care

If a mining site contains an approved mining waste facility such as a tailings pond, then closure and long-term care requirements pursuant to the metallic mining waste code [Ch. NR 182, Wis. Adm. Code] apply. Closure requirements must be compatible with the reclamation plan and costs must be included in the reclamation bond. Closure extends to the time at which a certificate of completion of reclamation for the entire waste facility is formally issued at which time the long-term care period is initiated (Grefe and Lynch, 1986). The long-term care period runs for 40 years after closure [Wis. Act 31, 1989].

LONG-TERM LIABILITY

In the 1979-1980 legislative session, Chapter 353, Laws of 1979, the mining damage fund [Wis. Stats. 107.30 - 107.35] was created which allows injured parties to recover damages for mining-related injuries through a no-fault process regulated by a state agency. Prior to the passage of Act 353, persons harmed by mining operations in Wisconsin found it difficult to recover damages because there were a number of obstacles that blocked or hampered the recovery of mining-related damages, namely: 1) parent corporations are generally not liable for injuries caused by subsidiaries; 2) a company which creates a dangerous condition on land is not liable for harm that condition causes after the land is sold; 3) negligence must be proven if damages are to be recovered even if causation is shown; 4) damage caused by an activity may not be discovered until expiration of the period during which a suit may be brought; and 5) the expense and uncertainty of court litigation can prevent people with small claims from obtaining full compensation (Schreiber, 1977).

The Mining Damage Reserve Accumulation (mining damage fund), initially funded from general purpose revenues, receives 4 percent of the total metallic mining tax receipts from a net proceeds occupational tax on mining of metallic minerals to to pay awards under the program. Mining-related injuries are defined as death or injury to persons or property caused by either: 1. Environmental pollution from emissions, seepages, leakages or other discharges from mine excavations or mining wastes; or 2. Substantial surface subsidence from mine excavations [Chapter 353,

laws of 1979].

Actions to recover damages for mining-related injuries must be brought within three years of the date on which the death or injury was or should have been known. The date of injury is the date on which the evidence of injury is sufficient to alert the injured party to the possibility of injury. The injury need not be of such magnitude as to identify the causal factor. A claimant may recover compensation (up to a limit of $150,000 per claim) without regard to fault, if, upon hearing, he or she demonstrates mining-related injuries. If a claimant is awarded damages, the state may bring action against the mining company to recover the amount awarded the claimant. Any claimant also has the option to bring an action against the mining company in circuit court. Mining companies are liable for mining-related injuries regardless of any change in the nature of ownership of interest in the prospecting or mining site, refinery or smelter and regardless of any reorganization, merger, consolidation or liquidation affecting the mining company. Long-term liability does not apply to a mining site which closed prior to May 22, 1980 [Chapter 353, Laws of 1979].

In short, the long-term liability act provides that the claimant need only prove before The Department of Industry, Labor and Human Relations that he or she was injured and that it was caused by mining; there need be no evidence that the company acted in negligence. The program also provides that, if Wisconsin does find liability, the state government can then go against the mining company to collect the damages. Recovery can be made from the mining damage claim fund under the doctrine of strict liability up to a limit of $150,000 per claim for a private injury to a person or property. Again, it is noteworthy from an environmental perspective that such a program exists for no other industry other than mining (Peshek, 1981).

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ASSESSMENT OF DATA QUALITY

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ABSTRACT

The quality of data can be evaluated on the basis of its uncertainty when compared with end-use requirements. The process by which acceptable data quality is evaluated is called quality assurance. In this paper, quality assurance, quality control, and quality assessment are discussed. Quality control samples generated in the field and laboratory are defined, frequencies of determinations are suggested, control limits and corrective actions are discussed. The PARCC (precision, accuracy, representativeness, completeness, and comparability) parameters are defined in terms of quality control samples and methods are given to quantify these parameters.

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INTRODUCTION

Environmental data are often the basis for critical decisions. These decisions may range from the protection of natural resources, to defining areas of contamination at Superfund sites, to the health of individuals. Data used for these purposes must be reliable and there must be evidence which proves its reliability. Most environmental measurements today are being generated using complex computer controlled instruments and sophisticated data processors. We can easily be misled that data are therefore automatically accurate and precise. This may not always be the case.

Reliable data must be supported by statistical statements of the confidence that can be placed in it. Reliable data requires a systematic approach to measurement and to control of the measurement process using quality control protocols.

How do we determine if data are of acceptable quality? What is acceptable quality? The quality of data can be evaluated on the basis of its uncertainty when compared with end-use requirements. The end-use requirements are established using an appropriate model to solve a problem. These end-use requirements are set by the project planners and data users prior to sampling and analyses. If the data are consistent and the uncertainty is small compared to the end-use requirements, then they are considered to be of acceptable quality. When data are excessively variable or the level of uncertainty is outside the end-use requirements, then they are of low or inadequate quality. Data quality is therefore a relative determination, and what is considered high quality in one situation may be inadequate in another.

The process by which acceptable data quality is evaluated is called quality assurance.

Quality Assurance: A system of activities designed to provide data that meet specific standards of quality with a stated level of confidence.

Quality Assurance has two separate but related parts: quality control and quality assessment.

Quality Control: A system of activities to control the quality of data to meet the project planner's and end-user's needs.

Quality Assessment: A system of activities to assess whether the overall quality control is operative.

This entire process of quality assurance, quality control, and quality assessment begins with a properly designed and consistently implemented Quality Assurance Plan. Figure 1 shows the major components of a project plan including quality assurance plan. Project planners and end users of the data prepare the QA Plan. This is a written document which defines the quality control and quality assessment protocols necessary to achieve the objectives dictated by the intended use of the data.

The Quality Assurance Plan addresses the sampling procedures to be used by the field sampling team. It defines calibration procedures, analytical protocols, and data reporting requirements for the laboratory personnel, and it provides data assessment methodologies to be used by the data reviewers in generating quality assurance reports. The quality assurance reports define the actual quality of the generated data and this is then compared to the data quality objectives.

Data quality objectives are defined levels of quality and quantity required for the data. They are based on the intended use of the data, available laboratory procedures and available resources. Figure 2 schematically shows the major components of the data quality objectives. The samples are defined in terms of matrix type (i.e. groundwater, surface water, soils, animal tissues, etc.) and number of samples to be collected. As part of the project planning sample locations, frequency of sampling and other important considerations are specified. Next, the analytes of interest are identified for each matrix type. The required detection limits for each analyte in each matrix type are established. Based on the required detection limits, an appropriate analytical technique is then chosen. The analytical technique must be able to qualify and quantify the analytes of interest at the required detection limit(s) and it must be able to achieve the stated control limits for the quality control samples. Considerable effort must be made to communicate with the laboratory regarding appropriate detection limits and analytical technique.

Quality control samples are defined in terms of those generated in the field (field standards, field blanks, field replicates) and those generated in the laboratory (matrix spikes, laboratory duplicates, laboratory blanks, all types of standards, and other performance samples). For each type of quality control sample, the frequency at which they are to be analyzed is stipulated; control limits are established and corrective actions are set when the quality control sample results are outside the control limits.

Table 1 shows an example of the type of information associated with quality control samples for the analysis of inorganics. The types of quality control samples are not all inclusive, but provide several which are most often used in modern instrumental analyses. The frequencies of analysis of the quality

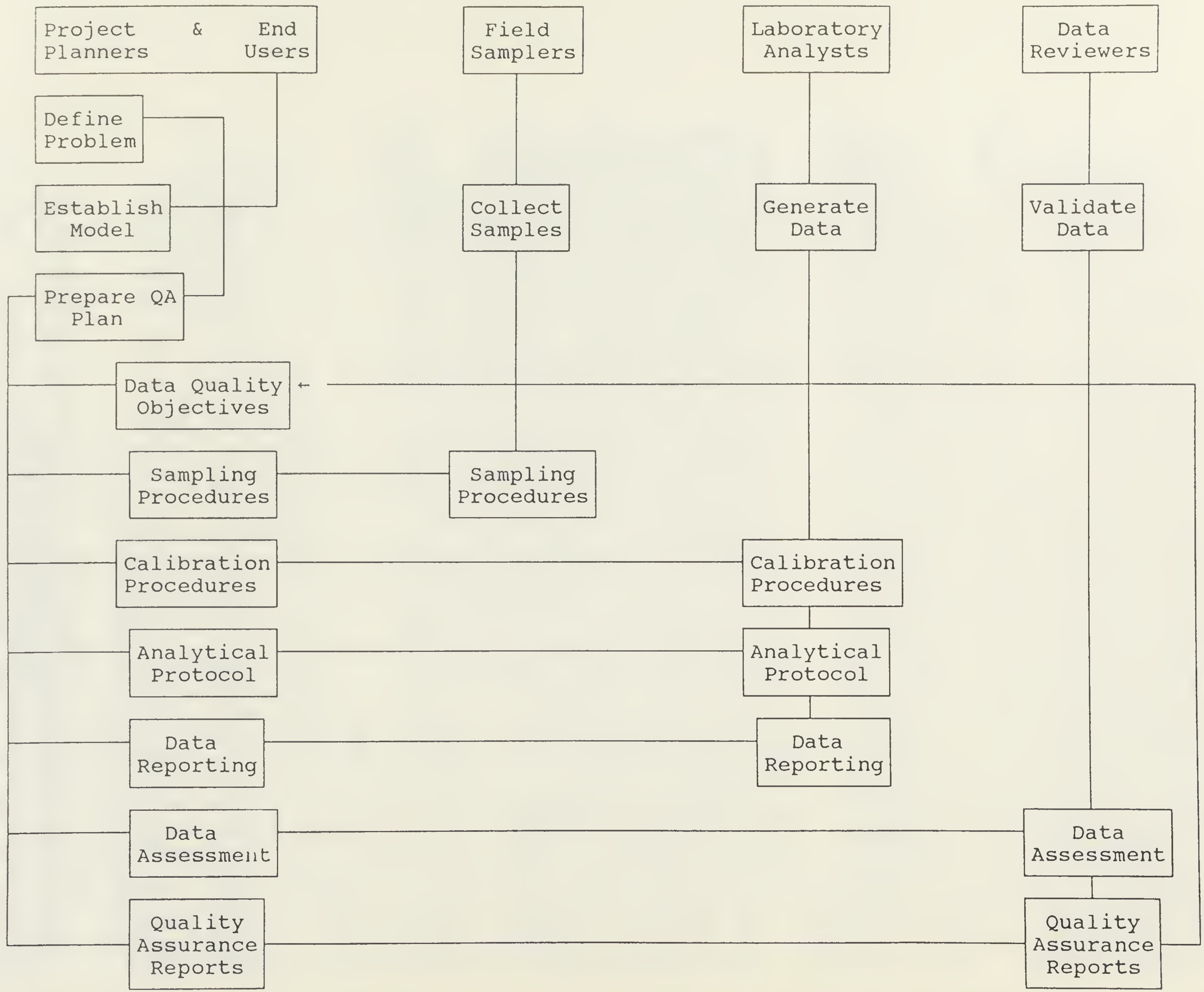


Figure 1. Schematic of Quality Assurance Program.

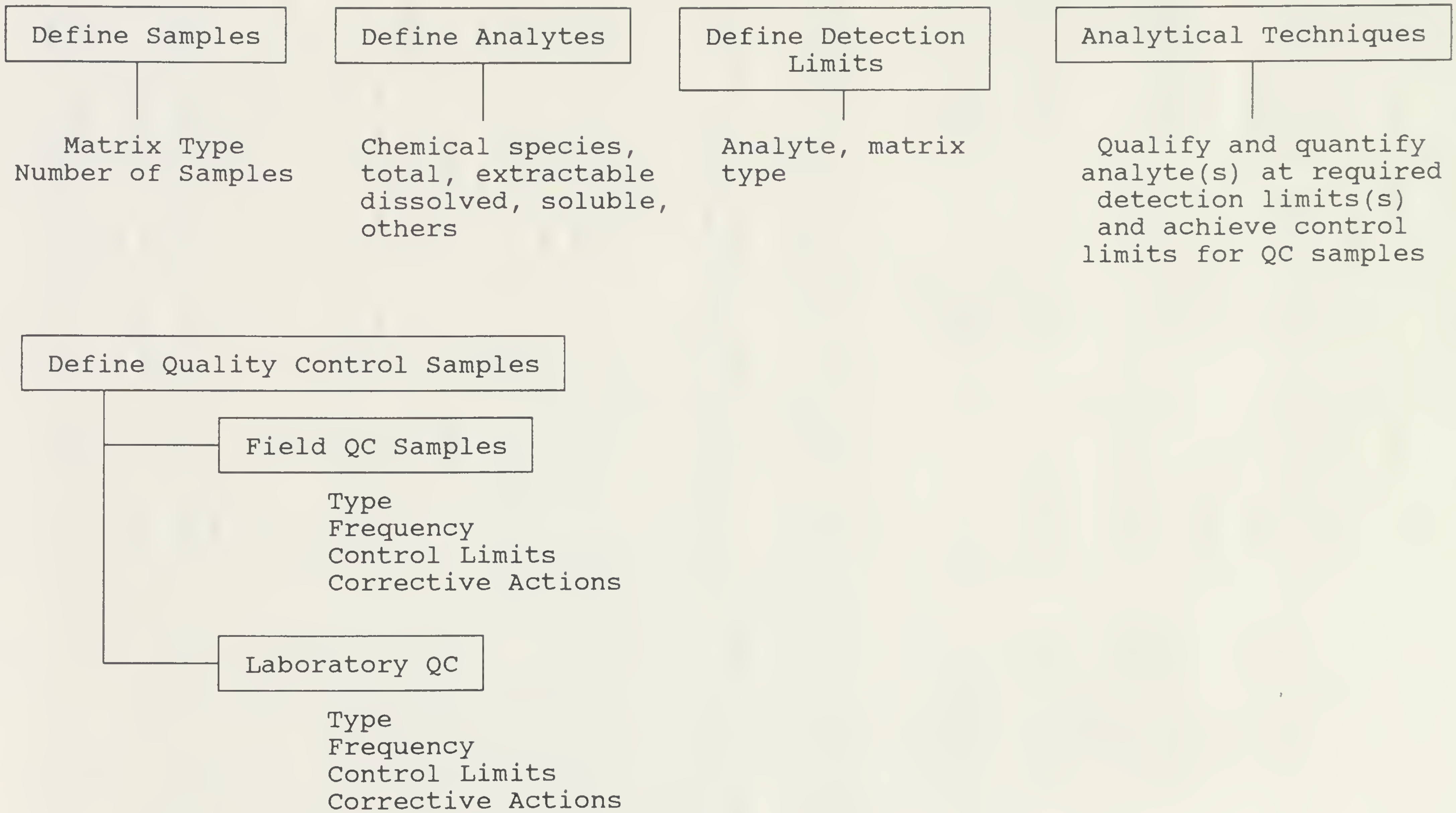


Figure 2. Data Quality Objectives.

Table 1. Quality Control Samples - Types and suggested frequencies, control limits and corrective actions*.

	Types	Frequency of Analysis	Control Limits	Corrective Actions
Laboratory QC Samples	Calibration Standards	Beginning and 10%	90-110% Recovery	Repeat calibration
	Calibration Blanks	Beginning and 10%	<IDL	Repeat calibration
	Instrument Performance Checks	Beginning, end	As Specified	
	Matrix Spikes	5%	75-125% Recovery	Repeat, qualify data
	Laboratory Duplicates	5%	±20% RPD	Repeat, qualify data
	Special QC Routines - Analytical Spikes - Methods of Standard Additions	As specified in analytical technique	As Specified	Repeat, qualify data
	Preparation Blanks	With each set	<IDL	Reanalysis, qualify data
	Reference Materials	With each set	90-110% Recovery	Reanalysis, qualify data
Field QC Samples	Field Duplicates	5%	±35% RPD	Evaluate as outlier
	Field Standards	5%	75-125% Recovery	Evaluate as outlier
	Field Blanks	5%	<IDL	Qualify data
	Interlaboratory Samples	5%	As Specified	Repeat sampling

* The suggested frequencies, control limits, and corrective actions are given as examples. The needs of the data users will more specifically define them.

control samples are suggested and can vary with the needs of the data users. A 10% frequency means that one quality control sample is analyzed with every ten field samples.

The control limits exhibited in Table 1 are also suggested; they may be more or less restrictive depending again on the user's needs. The corrective actions given in Table 1 are generalized, and in practice they are specifically stated. The laboratory is responsible for all quality control samples associated with the actual determinations. Data for the field samples must be generated while the measurement process is in statistical control - that is, the instrument (measurement process) must be in calibration as demonstrated by the results of calibration standards and calibration blanks being within their stated control windows. The calibration must be verified at a set frequency. Any data generated for field samples outside the calibration or when the measurement process is not in control are unreliable. Certain instrumentation may require the use of specific quality control samples that are used to ascertain that the measurement process is actually being done correctly. For example, the determination of metals by inductively coupled plasma emission spectroscopy (ICP) requires that any potential spectral interference be measured and corrected. Special ICP interference quality control samples which contain common analytes and their potential interference elements are analyzed and results must be within specified control limits or appropriate corrective actions

are applied. The laboratory is also responsible for the preparation blanks. This quality control sample contains all reagents used to prepare the field samples and is processed identically as the field samples. Exceeding the control window for any analyte may be caused by laboratory introduced contamination. Corrective actions usually include repreparation of the field samples associated with a contaminated preparation blank.

Laboratory accuracy can be measured using two types of quality control samples; matrix spikes and the analysis of reference materials. Matrix spikes are prepared in the laboratory by splitting a sample and adding a known amount of analyte(s) to one portion prior to digestion (for total constituent analysis). The sample results and spike sample results are compared and a percent recovery calculated. Laboratory accuracy can also be assessed by analyzing standard reference materials of the same matrix as the natural field samples. The reference materials may be interspersed with the field samples and submitted blind to the laboratory and/or directly by the laboratory as known standards.

Precision of data may be evaluated by analyzing laboratory duplicate samples (a field sample split in the laboratory prior to preparation) and field replicate samples (a field sample split in the field) and both submitted blind to the laboratory. Field blanks are samples used to evaluate potential contamination resulting from sample containers and those used to evaluate potential contamination resulting from decontamination protocols used to clean field sampling equipment. The frequency of insertation of the field generated QC samples is suggested at 5% (Table 1). The QC samples must be submitted with the natural samples in such a manner that they can be associated with a specific group of samples. In this way, any QC sample results which may be outside set control windows are clearly associated with certain field samples. This is of particular importance for the field blanks.

The last type of field QC sample listed in Table 1 is interlaboratory samples. These are natural samples and field QC samples split in the field and submitted to separate laboratories. Comparison of results from the two laboratories may be used to evaluate interlaboratory accuracy and precision.

The control limits provided in Table 1 establish the acceptability of the data. For example, if a control limit of 75-125% recovery is stipulated for laboratory spike analysis and this goal is achieved, the data are of acceptable quality (for this parameter). If the control limit(s) are not achieved, then the data are not considered to be wholly acceptable. During laboratory determination, QC samples outside the acceptance window along with their associated natural samples, can generally be repeated until the acceptance windows are achieved. In some cases, this may not be possible and a system for

qualifying out-of-control data should be established. A good example of a data qualifier system is one used in the EPA Contract Laboratory Program which is described in Laboratory Data Validation: Functional Guidelines for Evaluating Inorganics Analyses.

After data are received from the laboratory, the quality assessment portion of quality assurance begins. Data assessment entails review of the raw laboratory and the QC data to verify that the measurement process was operating within required control limits, analytical results were correctly transcribed, and which, if any, natural samples are related to out-of-control QC samples. The objective of this assessment is to identify any unreliable laboratory measurements and to qualify any affected data.

The quality of the data is then quantified in terms of the PARCC parameters. The PARCC parameters are precision, accuracy, representativeness, completeness, and capability.

Accuracy: degree of agreement of a measured value with the true or expected value

Precision: degree of mutual agreement characteristic of independent measurement

Completeness: measure of the amount of data obtained compared to the amount expected

The QC samples used to quantify accuracy, precision, and completeness and the protocols for quantification are provided in the Quality Assurance Plan. The QC samples used to quantify accuracy are laboratory matrix spikes and blind field standards. Those used to quantify precision are laboratory duplicates (analytical precision) and field replicates (analytical and field variability). Completeness can be quantified from the number of valid samples (reliable data), the number of planned samples, and the actual number of collected samples.

Representativeness: degree to which data accurately and precisely represent a characteristic parameter

Representativeness is difficult to quantify as it is concerned with an appropriate sampling scheme. Representativeness is accomplished by choosing the number of samples, locations and sampling procedures that depict the matrix and conditions being measured. These considerations must be addressed in detail in project planning documents. One part of representativeness is quantifiable. Potential contamination resulting from sampling is bias which impacts representativeness. If contamination is significant, then our field samples

may not be truly representative of what is measured. Quality control samples used to assess bias from contamination are field blanks including bottle blanks and decontamination blanks.

Comparability: confidence with which one set of data can be compared to another

This PARCC parameter is the most difficult to quantify. In most Quality Assurance plans and other project planning documents, comparability is addressed by evaluating existing data, using similar or identical sampling techniques, identical analytical procedures, and by using similar or identical quality assurance programs. Except under special circumstances, comparability is usually a qualitative statement.

Accuracy of the data can be quantified from the recovery of the analyte in each type of QC samples: blind field standards and laboratory spike analyses. In each case, the mean recovery and confidence limits can be computed providing accuracy statements based on each type of QC sample.

Precision of the data can be quantified from the results of the laboratory duplicate analyses and the field replicate analyses. In each case, an overall relative standard deviation and confidence limit can be generated providing precision statements based on each type of QC sample.

Completeness can be calculated in two ways: as a percentage of the number of samples having valid (reliable) data divided by the number of proposed samples; and, as a percentage of the number of samples having valid (reliable) data divided by the number of samples actually collected.

Any bias resulting from contamination in the field is assessed by comparing field blank data to defined instrument detection limits. Blank values greater than twice the detection limit represent significant potential contamination, and associated sample values less than five times the detection limit may be impacted.

After the PARCC parameters have been quantified, they are compared to the goals for data acceptability as defined in the data quality objectives (Figure 1). Data that meet the goals can be used in the decision making process for which the samples were collected and data generated. Data that do not meet the goals may not be used for decision making as they do not satisfy the end-use requirements initially established. In these cases, it may be necessary to redefine the initial problem, make changes to the model, change the data quality objectives, resample and reanalyze. To avoid this very costly iterating process, it is important that each step of the process is clearly defined so that quality data meeting the objectives and end-use requirements are achieved.

Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

COMPARING FOUR METHODS OF SELENIUM ANALYSIS INVOLVING PLANT DIGESTIONS[1]

Roger N. Pasch, Alan Telck, and Carlton Peterson[2]

ABSTRACT

Two species of plants were grown in three levels of selenium rich soils. Plants were harvested and digested using a 4:1 nitric-perchloric acid mixture. Each digestion was then analyzed using 1) AA Hydride 2) AA Furnace Method 3) ICAP Direct Aspiration and 4) ICAP hydride method. It was found that ICAP hydride showed the best correlation and had the highest NBS recoveries for selenium analysis in plant digestions.

[1]Study was completed at Inter-Mountain Laboratories and paper presented at the 1990 Billings Reclamation Symposium, March 25-30, 1990.

[2]Roger N. Pasch, Mining Soils Coordinator, IML. Alan Telck, Senior Soils Analyst, IML. Carlton Peterson, Trace Metals Analyst, IML.

INTRODUCTION

Commercial laboratories use two major types of equipment to determine Selenium concentration. Atomic absorption (AA), using furnace or hydride generation, and Inductively Coupled Plasma (ICP) are the most common (Kikuo Tarada 1975). This study is an attempt to evaluate these two instruments using the four methods for selenium determination - AA furnace, AA hydride, ICP direct and ICP hydride. An acid digestion using a 4:1 nitric and perchloric acid ratio was incorporated for decomposing the plant material. Plant species were chosen and grown in naturally occurring selenium soils, harvested, and analyzed using the four methods. Several samples of the typical overburden chemical matrix were sampled from a southern Powder River Basin coal mine in the early spring of 1989. The two types of material were collected from spoil piles before regrading. A third soil material was collected in central Wyoming.

The first sample was a light gray clay shale. The standard Wyoming Overburden Guideline analysis (Wyoming DEQ 1984) was completed and all the parameters were suitable according to the 1984 criteria to establish suitability. The second sample collected was a dark gray shale. This overburden, located above the coal seam, had visible coal-like material inte[illegible]ed with light clay and dark shale material. The analysis of this sample did have one parameter that is considered unsuitable, and that was a total organic carbon content of 19.4%. One parameter, selenium, had a marginal reading of 0.10ppm water soluble selenium.

A third sample of material was also incorporated in the study. The sample was collected at the Chauk Bluff Poison Draw Drainage near Lysite, Wy. The Chauk Bluff sample had several chemical characteristics above the suitability limit according to the Wyoming DEQ guidelines. The parameters were EC of 9.42, saturation percent of 202%, SAR of 31.5, and selenium of 56.5. The third sample, although not a typical overburden spoil for the Powder River Basin coal fields, did have the characteristics of a high native water soluble selenium content. Results of the chemical characteristics of these three samples are found in Table 1.

The samples were then prepared for a greenhouse study involving western wheat grass (Agropyron Smithii, cv. Rosanna) and alfalfa (Medicago Sativa, cv. Ladick). Each type of soil was dried and hand processed through a -10 mesh sieve. All material was then thoroughly mixed

Table 1.

CHEMICAL CHARACTERISTICS OF SOILS USED IN THE SELENIUM STUDY

	pH	EC	Sat %	Ca	Mg	Na	SAR	VFS	S %
LT CLAY SHALE	7.80	1.91	35.67	2.87	2.70	11.80	7.07	23.05	38.50
DK CLAY SHALE	5.60	3.87	67.87	17.20	12.20	15.70	4.09	17.61	39.50
RED-CHAUK BLUFF	7.80	9.42	202.31	9.87	1.05	73.50	31.46	13.47	15.80

	Sl %	Cl %	Texture	OM %	TOC	TS %	AB	NP	ABP
LT CLAY SHALE	41.10	20.40	LOAM	0.39	3.23	0.06	1.87	36.89	35.02
DK CLAY SHALE	21.00	39.50	CLAYLOAM	4.24	19.40	0.43	13.43	8.50	-4.94
RED-CHAUK BLUFF	16.60	67.60	CLAY	0.38	2.29	0.17	5.31	12.17	6.86

	SO4S	PyrS	OrgS	PyrS AB	PyrS ABP	B	Se	Mo	NH3
LT CLAY SHALE	-0.01	-0.01	0.06	-0.01	36.89	0.15	0.08	-0.05	9.98
DK CLAY SHALE	0.06	0.14	0.23	4.37	4.12	1.38	0.10	0.05	13.46
RED-CHAUK BLUFF	0.11	0.05	0.01	1.56	10.61	0.13	56.50	0.05	6.29

	AvaNa	ExcNa	CECBow	ESP
LT CLAY SHALE	1.63	1.21	15.70	7.70
DK CLAY SHALE	2.25	1.18	34.80	3.40
RED-CHAUK BLUFF	36.30	21.43	63.00	34.02

and split into sub samples for pots. Six pots of light gray shale were set up, three with western wheat grass and three with alfalfa. Six pots of dark gray shale were set up; again, three with western wheat grass and three with alfalfa. In addition, twelve more pots were made, six with 1:1 mixtures of light gray shale and Chauk Bluff sample and six with 1:1 mixtures of dark gray shale and Chauk Bluff samples. Each type of mixture was then set up with three western wheat grass and three alfalfa. The pots measured 20cm across the top and 17cm across the bottom. Height was 19.5cm. All of the pots were plastic and had no drainage holes in the bottom. For comparison, two groups of samples were picked to use in pots with drainage holes. They were the light gray shale and the 1:1 mixture of light gray shale and Chauk Bluff samples. A total of three cuttings of plants were used in the study.

The purpose of the study was to start plant seeds in a greenhouse condition, harvest the material, and analyze the acid digestion of the plant material using four different methods of analysis: 1) ICAP direct, 2) ICAP hydride, 3) AA Hydride, and 4) AA Furnace.

In addition, each soil was sampled and analyzed for selenium. Each extraction or digestion was split and analyzed by all four methods. A control sample, NBS Standard 1567A wheat flour, was analyzed with each set.

METHODS OF ANALYSIS

Atomic absorption hydride generation was done using a Varian 775AA and a model 64 hydride kit. The Varian 775AA uses a N_2H_2 flame for hydride generation. The nebulizer is replaced with a plastic adapter and the hydride gas, when generated, is forced through the flame itself. Wheaton bottles were used for each sample and standards. Peak height was recorded on a chart recorder. All extracts were treated with HCl and H_2O_2 to convert all forms of selenium to the +4 state (Workman, S.M. 1980). The wavelength used was 196.0nm with D2 background correction.

The ICAP 61 Comp. Thermo Jarrell Ash machine was fitted with a hydride adapter kit (Soltanpour 1979) to generate hydride analysis. The kit, perfected by Allen Telck, uses a peristaltic pump to combine the Sodium Borohydride solution and HCl in a mixing chamber. The selenium hydride is then introduced into the plasma and is analyzed. The computer then records the intensities of the sample and converts them to PPM readings. This

method also requires the pre-treatment of all extracts using HCl and H_2O_2 before analysis.

The ICAP was also used for selenium analysis without hydride configuration. It can scan all samples for selenium. High level samples can be analyzed using direct aspiration. In this case no pre-treatment is necessary. One draw back to this method is that only high level samples can be run. The wavelength used was 196.0nm.

The fourth method for determining selenium was the AA furnace or carbon rod analysis. The method has been approved by the EPA for Se analysis in drinking water and CLP analysis involving 3050 digestions. The method calls for Palladium Chloride to be added as a modifier to all the samples to assist in the selenium analysis. This method of analysis appeared in Spectroscopy Vol.4 No.2. The instrument used was a Thermo Jarrell Ash Video 22 with Smith-Hieftje background and a wavelength of 196.0nm.

PLANT DIGESTIONS

Plant samples were digested using a 4:1 nitric-perchloric mixture. A total of 10 mls of the acid mixture was used. Taylor digestion tubes (50ml) were used in a 45 hole aluminium digestion block. Samples were heated at 125C until 2-4 mls of the original amount of acid remained. At this point the solution was colorless and was then diluted with deionized water to 50 mls. The solutions were then analyzed on each instrument.

ANALYSIS OF METHODS FOR SELENIUM DETERMINATION

Since the levels of selenium detected ranged from low to very high, several comparisons can be made. To compare the 3 cuttings with the 4 methods of analysis, graphs showing the relationship between the 4 methods of analysis and the three cuttings are presented in Figures 1-3. The graph in Figure 4 compares the hydride AA and the Hydride ICAP analyses. All 84 samples are used in the comparison which covers a full range of values for selenium. The final value concentrations range from 0.75ppm to 645ppm. A correlation coefficient of the two methods calculate out to be a 0.918. The Varian hydride

Figure 1.
Selenium Analysis - First Cutting
All Samples

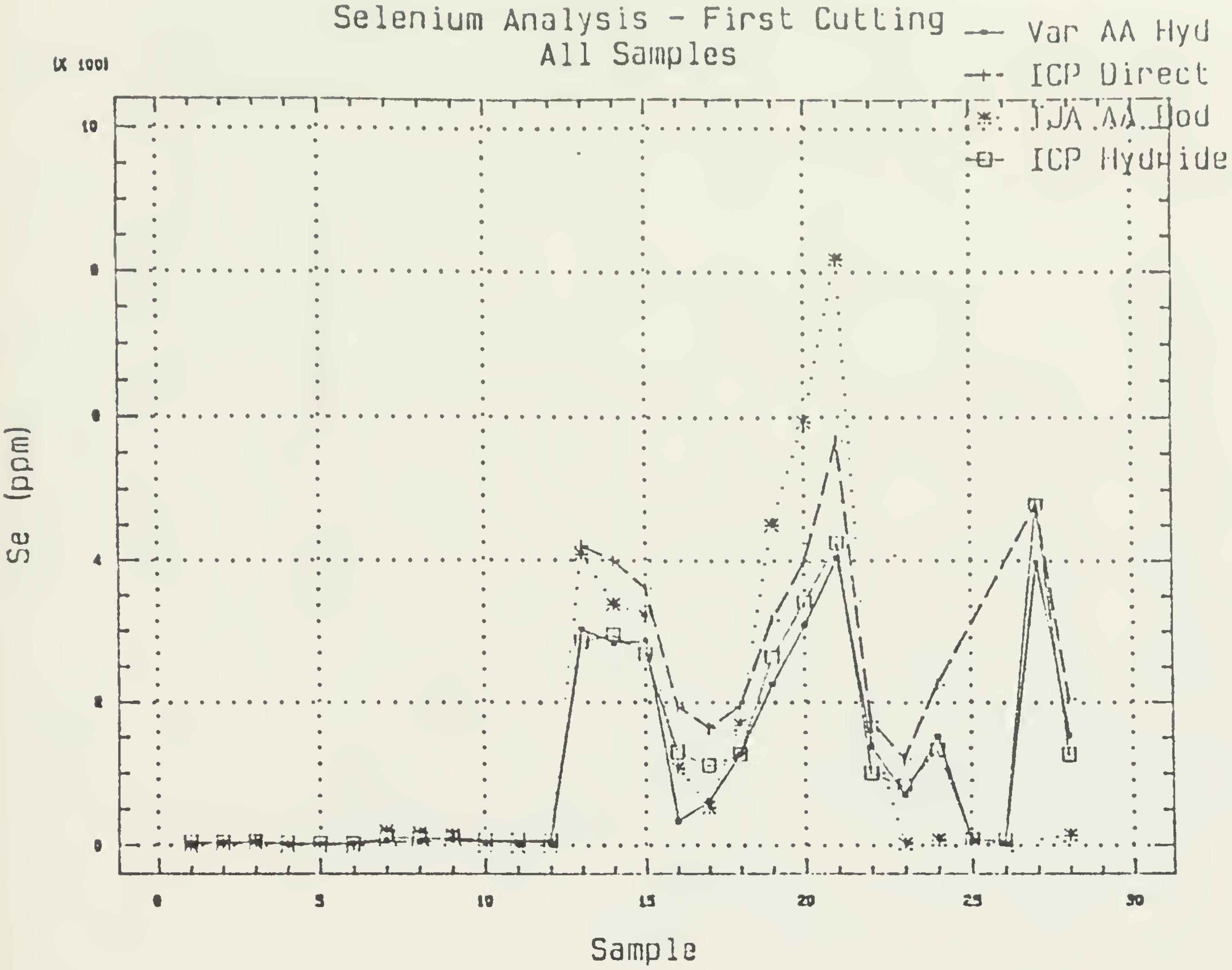


Figure 2.
Selenium Analysis - Second Cutting
All Samples

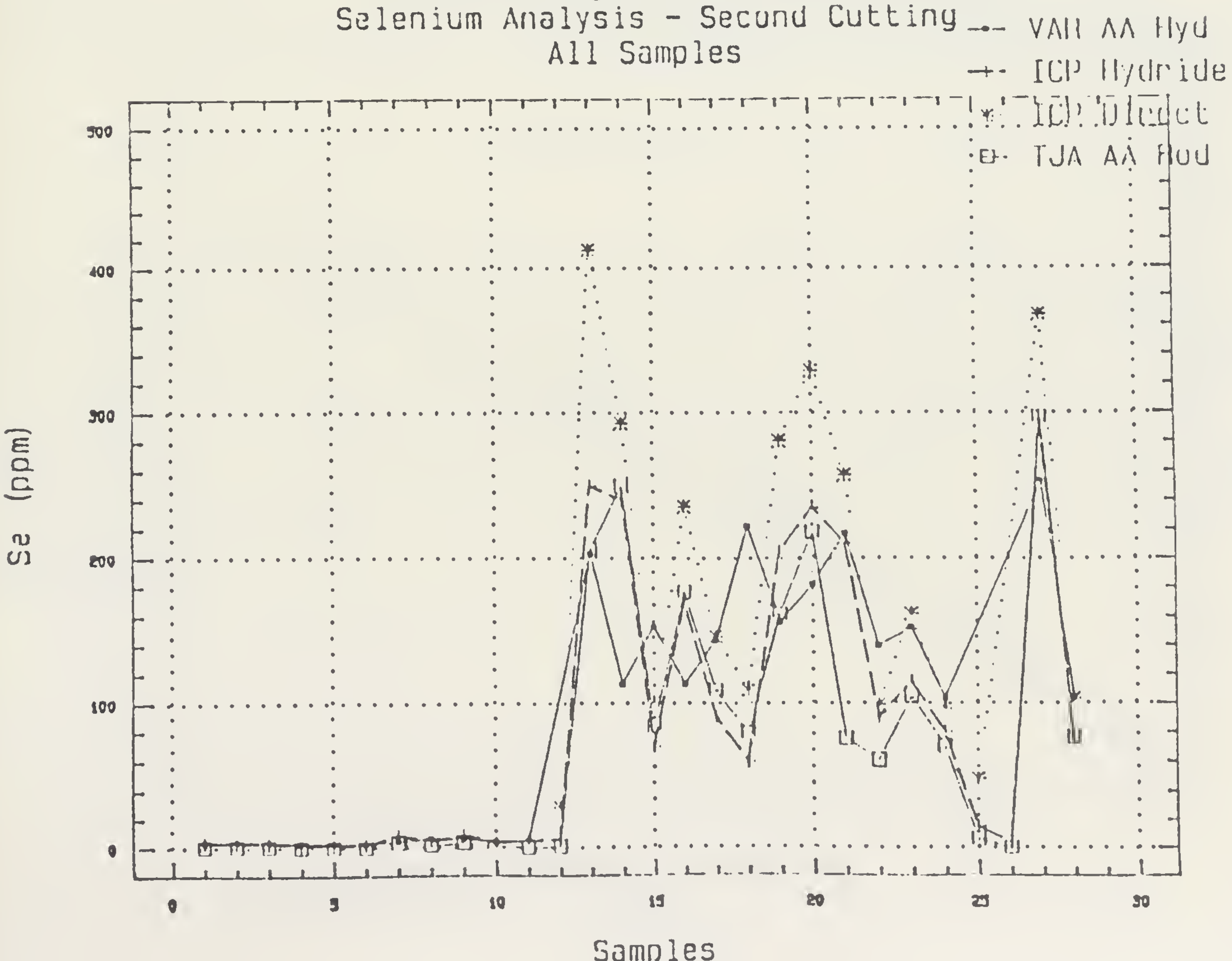


Figure 3.
Selenium Analysis - Third Cutting
All Samples

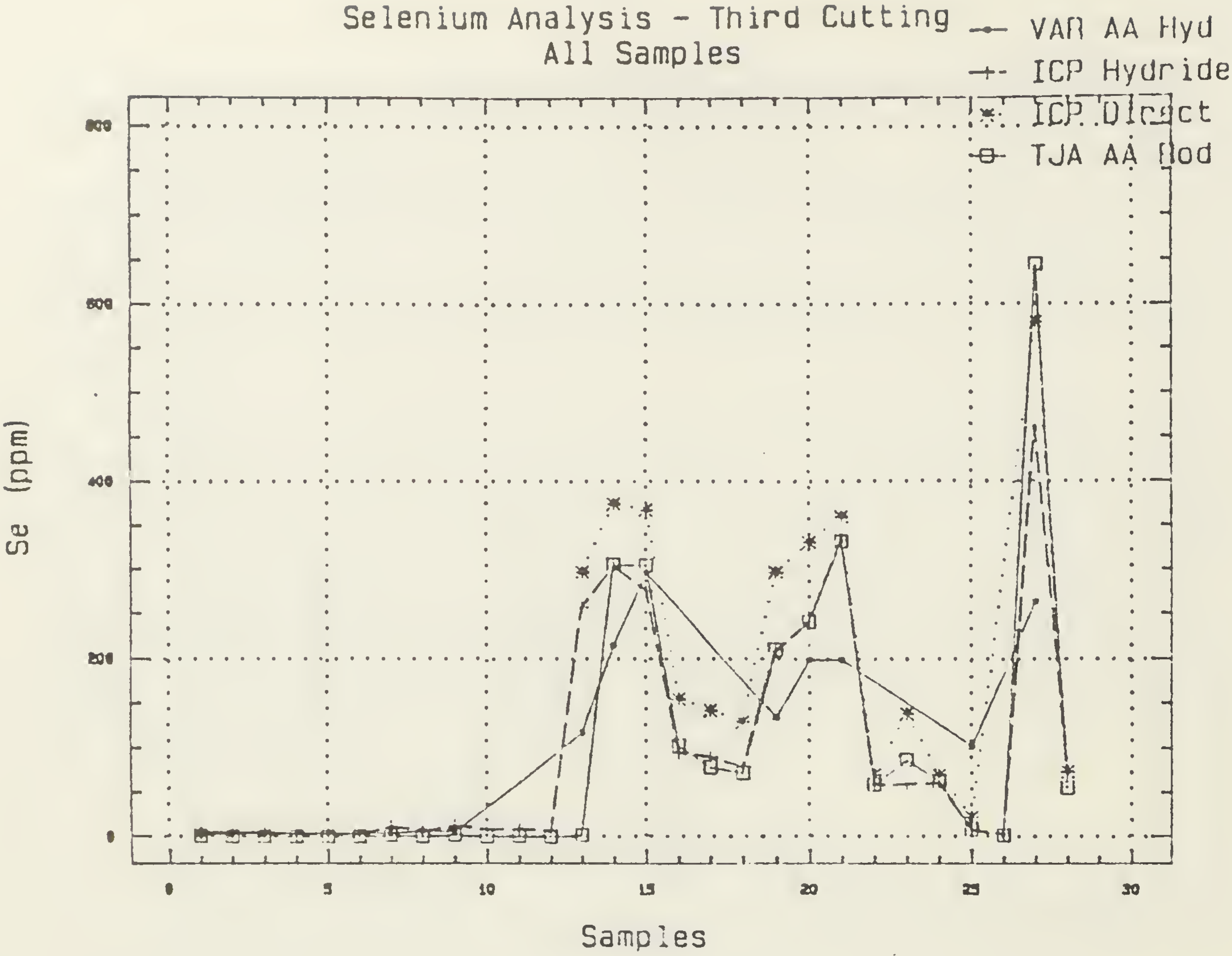
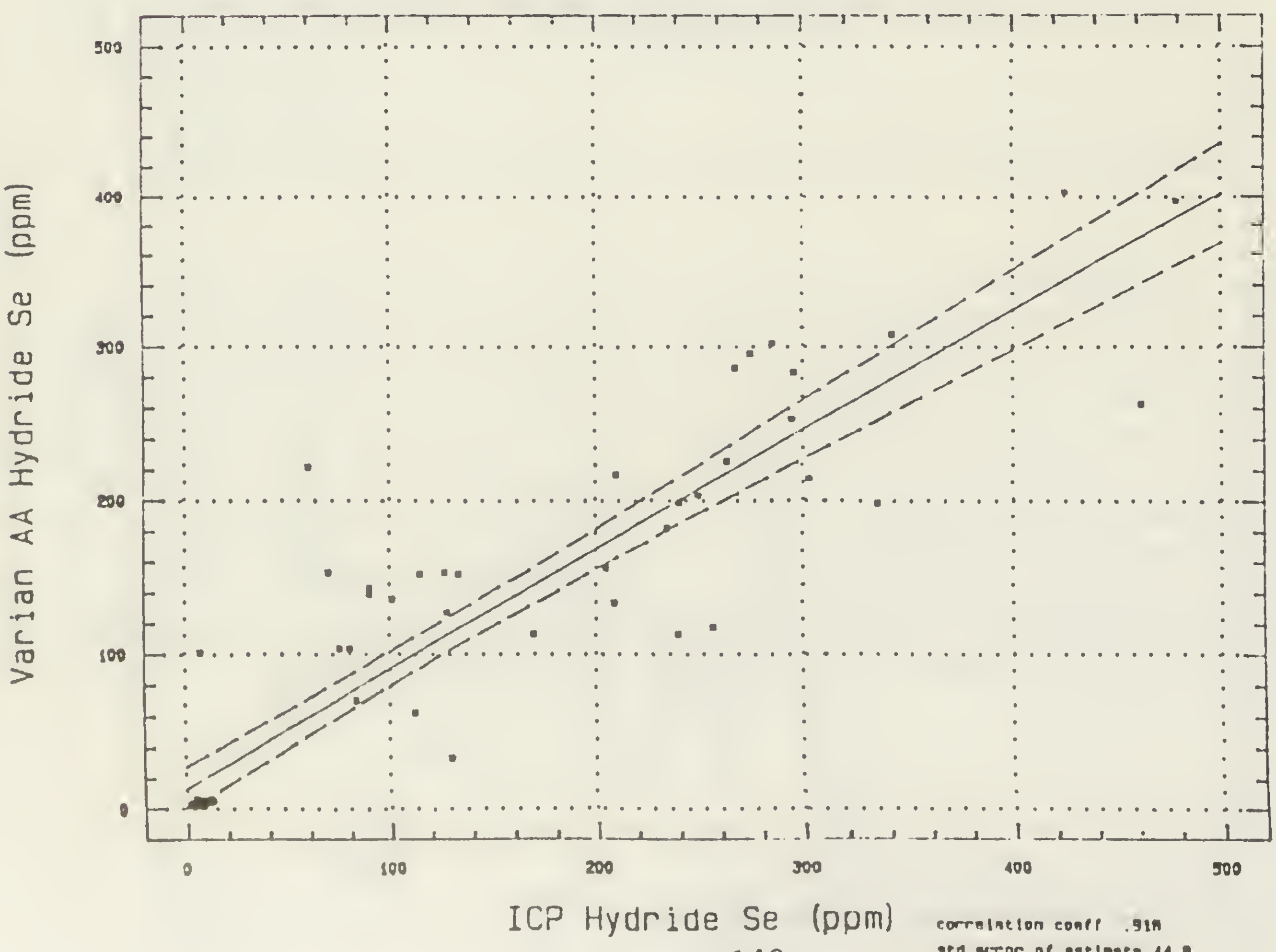


Figure 4.
Regression of Varian AA Hydride on
ICP Hydride Seleniums - All Samples



method uses a much shorter integration time (2 sec) than the ICAP hydride (10sec) due to the set up configurations. The ICAP allows considerable advantage in this step. Some new AA hydride kits allow similar flexibility in integration time which would probably show a better comparison.

The third comparison (Figure 5) is the TJA furnace method and ICAP hydride. This comparison is on samples containing less than 0.2ppm in solution. Scatter of the values seem to be the same as the other methods on low levels. During analysis, acid burn off produced considerable background interference. In several cases where low selenium values were recorded on ICAP hydride, interferences caused some numbers to be below the detection limits of the rod. The correlation coefficient of the two methods was 0.903.

The fourth method for comparison is between the ICAP direct and ICAP hydride. This comparison had a correlation coefficient of 0.974. Due to the poor detection limits of the direct ICAP readings, only the greater than 20ppm readings were compared. On the higher levels the direct method has a linear range of 0.4 to 100ppm. The range on hydride generation ICAP is from 0.002 to 0.200ppm. The sample that read 331ppm direct had to be diluted 1 to 30 to be in the most sensitive range. These two methods appear to have the best precision of the methods tested (Figure 6).

In comparing the control NBS standard on the three methods used for analysis, the ICAP hydride showed the best recovery. The results of % recoveries are listed in Table 2.

CONCLUSION

For the methods used in this study, a review of the data indicates the most reliable method to determine high and low levels of the selenium in plant digestions is ICAP hydride. Other extractions or digestions may be suitable for other instruments and give comparable results. Our laboratory has recently purchased two new hydride kits for AA analysis. Further comparison involving plant digestions, total and extractable soil selenium will be made to select the best method for the test required.

Figure 5.
Regression of TJA AA Rod on ICP Hydride
Seleniums - All Samples

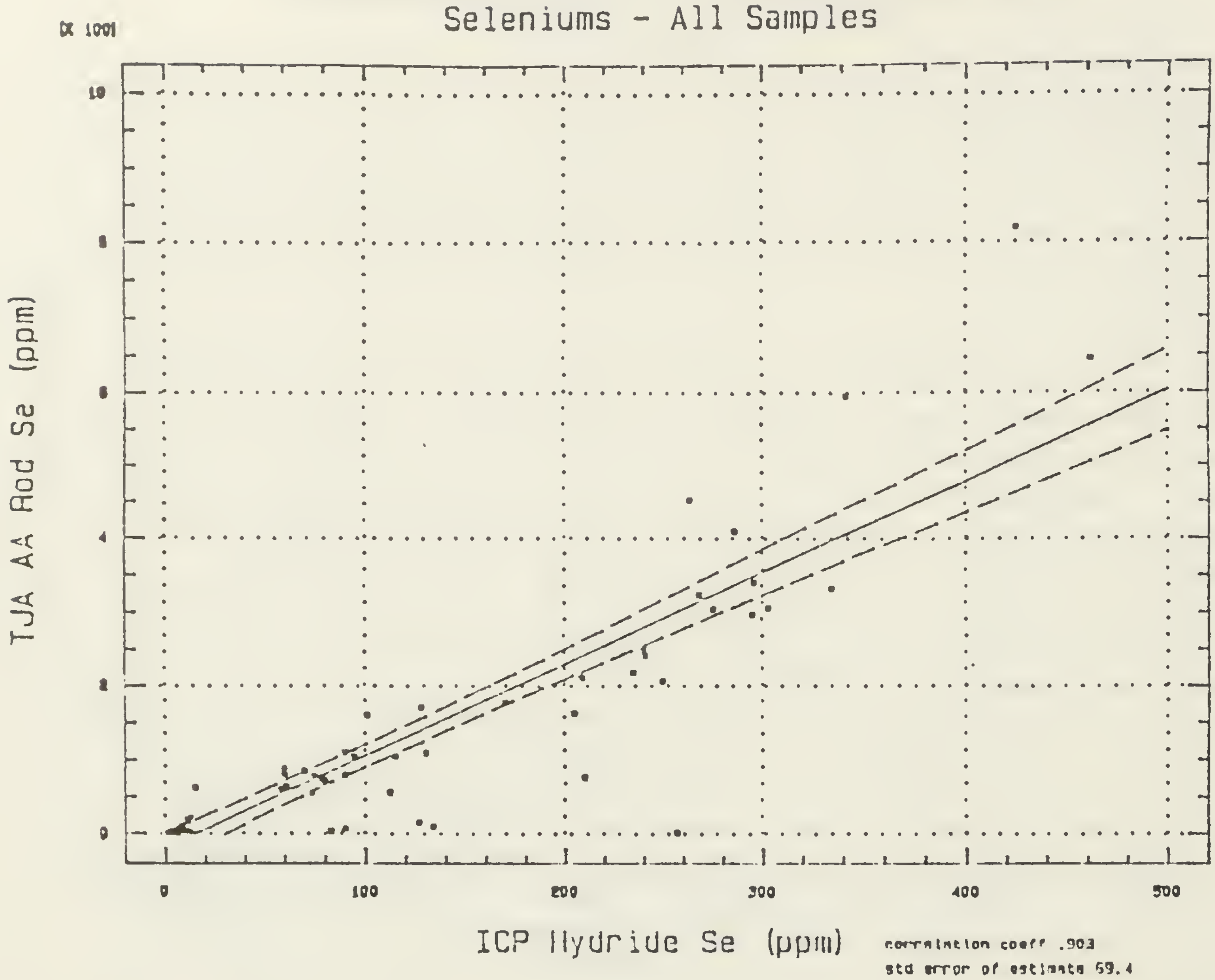


Figure 6.
Regression of ICP Direct on ICP Hydride
Seleniums - All Samples

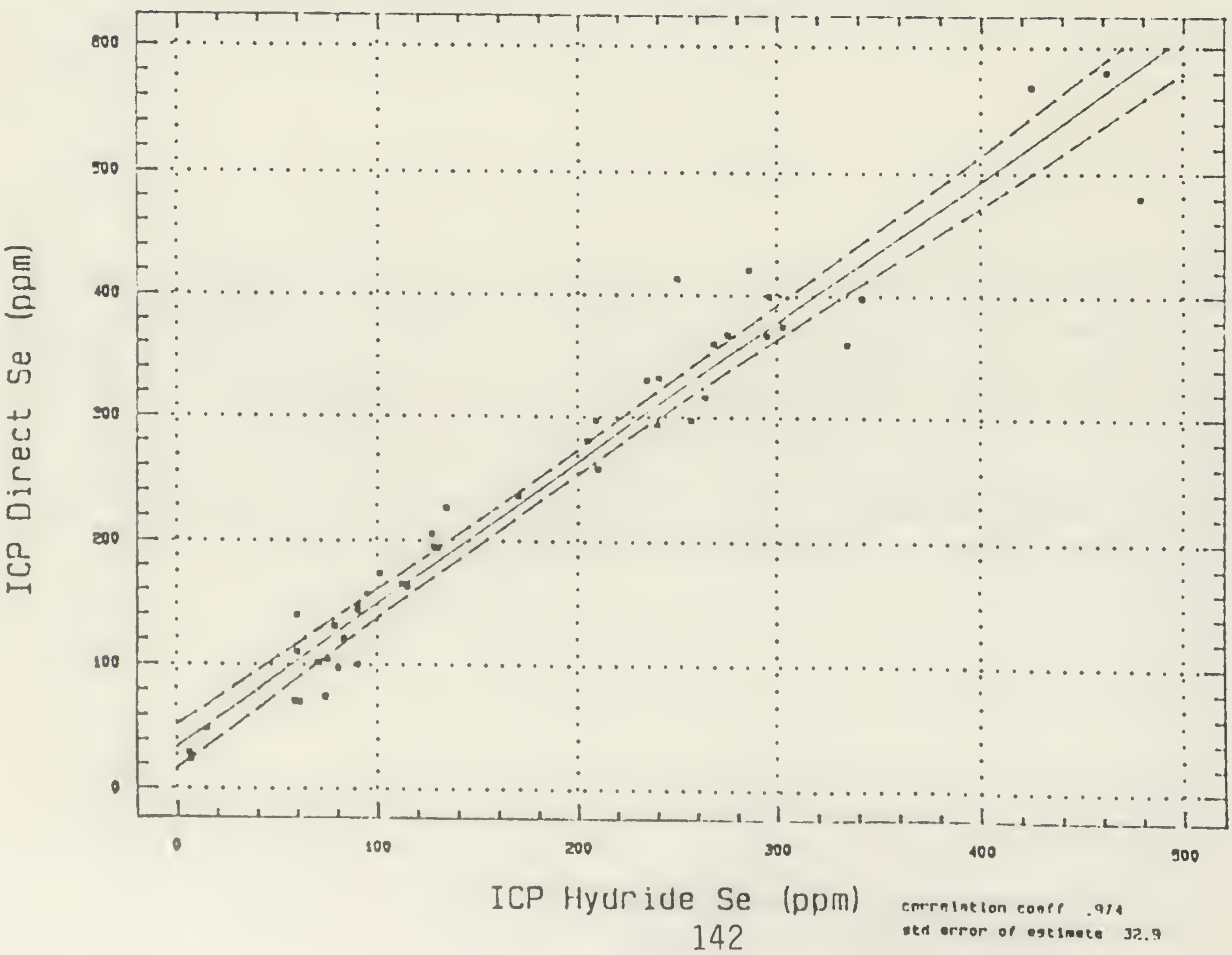


Table 2.

NBS Results of Wheat Flour 1567a

True value = 1.10 +/- 0.2

ICAP Hydride Method	Result	% Recovery
Run 1	1.18	107.3
Run 2	1.13	102.7
Run 3	1.08	98.2
Varian Hydride Method	**Result**	**% Recovery**
Run 1	0.94	85.5
Run 2	0.79	71.8
Run 3	0.96	87.3
TJA Furnace Method	**Result**	**% Recovery**
Run 1	0.93	84.5
Run 2	1.04	94.5
Run 3	0.82	74.5

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

EFFECT OF LANDSCAPE POSITION ON SPRING WHEAT YIELDS AND WATER USE

Gary A. Halvorson[1]

ABSTRACT

Research was undertaken to quantify the effect of topography on spring wheat yields on land undisturbed by mining in North Dakota. Three fields at one location and two fields at another location were monitored for four years for spring wheat yield and water use. Four soil series within each field were monitored. The Zahl soil series (Entic Haploboroll) is located on hilltops and shoulder positions, Williams (Typic Argiboroll) on side slopes and hilltops, Bowbells (Pachic Haploboroll) on footslopes and toeslopes, and Tonka (Argiaquic Argialboll) in small depressional areas. Topo factors were calculated at each site by measuring the slope in four directions, 90° apart and adding the slopes together. If a slope was downward toward a site, it was considered positive, if a slope was upward toward a site it was considered negative. This number, if positive would indicate that overall runon water would be added to the site and if negative water would be lost from the site due to runoff. Topo factors were calculated from 3, 6, 15, and 30 m from each site. As expected wheat yields from the four soils were in the order Tonka > Bowbells > Williams > Zahl. Wheat yields were generally related to total water use. When the topo factor was added into the regression of yield versus water use the coefficient of determination, R^2, increased in all cases. Topo factors measured 15 m from the site gave the best overall results.

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INTRODUCTION

Numerous studies have shown the influence of topography on crop yields (Ciha, 1984; Simmons et al, 1989; Stone et al, 1985; and Douglas et al, 1985). Some studies have emphasized how erosional losses in productivity are landscape dependent (Stone et al, 1985; Jones et al, 1989; and Daniels et al, 1985). Hanna et al (1982) among others have documented how topography redistributes water in the landscape. In a semi-arid area such as the northern Great Plains this becomes important because water is so limiting to crop production. In the northern Great Plains agricultural production is very dependent on the amount of water available to a growing plant. Bauer (1972) showed that stored water at planting or soil-water loss during the growing season plus the growing season precipitation are well correlated with yield of small grains. Because of runoff and runon of precipitation as well as saturated and unsaturated flow in the soil profile, water is not evenly distributed in the landscape.

Regulations in North Dakota require that land disturbed by mining be reclaimed to productivity equal to or greater than the premine land. Since the landscape is severely disrupted during mining it is difficult to compare land productivity before and after mining, without a good understanding of how topography affects crop yields. Studies of soil productivity in North Dakota on land reclaimed following mining have shown that topographic position influences crop yield. Doll et al (1984) summarized several studies in North Dakota where landscape position had an important influence on crop production on mined land. Wollenhaupt and Richardson (1982) presented evidence that even microtopographic differences can be an important factor in determining crop yields on reclaimed land.

In general, the studies of the influence of topography have been quantitative in nature and have categorized sites only by their morphologic landscape position. Very few have attempted to quantify the landscape effects on crop production. Sinai et al (1981) calculated a soil surface curvature factor from the elevation of neighboring points on a grid pattern of the field. This factor was positive in concave positions in the landscape and negative in convex positions in the landscape and correlated very well with soil moisture content. Simmons et al (1989) used a modification of this method to calculate curvature and slope which was then found to be significantly related to crop yields.

A study was undertaken to determine the best way to quantify the relationships of landscape to water distribution and crop yields. The ultimate goal of this research is to model and predict crop yields on unmined and reclaimed land based on factors such as soil water and landscape position which are important to crop production in the northern Great Plains.

METHODS AND MATERIALS

Two locations were selected for this study. The first was located 5 km west of the town of Underwood, North Dakota. Some preliminary yield data was collected in 1984 and a more intense study began in 1985. The location consisted of three fields in strips which, in total, encompassed about a half section or 130 ha. For the years 1984-1986 each of these fields had a crop rotation of fallow, wheat, sunflower. From 1987-1988 the fields were continuously cropped, but the seeded species alternated between wheat, sunflowers, and oats. The second location was about 10 km north of Beulah, North Dakota. Detailed measurements at this site began in 1985. This location consisted of 2 fields which, in total, consisted of about 65 ha and were alternately fallowed or seeded to wheat.

Soils at both sites were derived from glacial till. At the Underwood site four soil series were identified which represented different topographic positions in the landscape. The Zahl soil (fine-loamy, mixed Entic Haploboroll) is located on hilltops and shoulder positions in the landscape. The Williams soil (fine-loamy, mixed Typic Argiboroll) is located on hilltops and sideslopes. The Bowbells soil (fine-loamy, mixed Pachic Haploboroll) is found in footslope or toeslope positions. The Tonka soil (fine-montmorillonitic, frigid Argiaquic Argialboll) is located in small depressional areas. The Tonka soil series was not present at the Beulah location. Four sites of each soil series were located in each field. In 1986 one or two additional sites of each soil series were located in each field.

The soils were characterized for bulk density and soil water content to a depth of 1.2 m in 0.3 m increments. Soil water was determined gravimetrically from core samples taken approximately every three weeks during the growing seasons of 1985-1988. Wheat grain yields were determined from 5 subsamples taken at each site, each consisted of wheat from two drill rows 0.91 m long. The wheat grain was air dried and yields calculated on a per hectare basis.

The topo (topographic) factor was determined at each site. The slope was measured in four directions 90° apart from each other. If the slope in any one direction was downward away from the site it was designated as negative. If the slope was upward from the site it was designated as positive. The slope measurements from the four directions were then added together to give one number, designated as the topo factor. This topo factor should then be positive in landscape positions where a net increase in water would be expected from runon water or movement downslope within the soil profile. The topo factor should be negative in landscape positions where a net loss of water should occur from runoff and downslope movement of water in the soil profile. Topo factors were determined for measurements made at distances of 3, 6, 15 and 30 m from the site.

Water use was calculated from the difference in available soil water to a depth of 1.2 m at planting and at harvest plus the total precipitation. Wheat yields were regressed against water use. The topo factor was

used to adjust the water use for topographic effects using multiple regression techniques.

RESULTS AND DISCUSSION

Yields of spring wheat as expected were highest for the Tonka soil followed by Bowbells, Williams, and Zahl for the years 1984-1988 (Tables 1 and 2). Yields also varied considerably from year to year mainly because of differences in climatic conditions. Yields tended to vary more from year to year in the more productive Tonka and Bowbells soils than in a soil such as Zahl.

Table 1. Yields of spring wheat from a field near Underwood, ND.

Soil series	Location	Wheat Yield 1984	1985	1986	1987
		Mg/ha			
Bowbells	1	2.0	4.3	2.9	1.2
	2	2.9	3.6	3.0	1.3
	3	2.7	5.0	3.4	3.0
	4	2.3	2.8	2.1	1.0
	5			2.9	1.6
	6			2.8	1.9
	Average	2.5	3.9	2.9	1.7
Tonka	1	3.0	4.5	3.6	2.4
	2	3.5	5.0	3.2	1.8
	3	2.6	5.7	2.4	2.8
	4	2.2	4.7	2.5	2.0
	Average	2.8	5.0	3.0	2.2
Williams	1	2.2	3.6	2.2	1.4
	2	2.8	2.8	2.2	1.3
	3	2.4	3.1	2.0	0.9
	4	1.8	2.8	2.0	0.8
	5			2.6	1.2
	6			3.1	1.2
	Average	2.3	3.1	2.4	1.2
Zahl	1	1.9	2.4	2.3	0.8
	2	2.6	1.8	2.1	0.8
	3	2.0	2.6	2.2	1.2
	4	2.3	3.4	1.3	1.0
	5			1.8	0.9
	6			2.3	1.4
	Average	2.2	2.6	2.0	1.0

Table 2. Yields of spring wheat from a field near Beulah, ND.

Soil series	Location	Wheat Yield 1985	1986	1987	1988
		------------------Mg/ha------------------			
Bowbells	1	5.6	2.5	4.2	1.2
	2	5.1	3.1	3.2	1.4
	3	5.3	2.2	4.5	1.1
	4	4.3	4.0	3.8	1.8
	Average	5.1	3.0	3.9	1.4
Williams	1	5.2	2.3	3.8	1.7
	2	4.0	2.5	2.7	1.1
	3	5.1	2.5	3.0	1.6
	4	4.3	3.5	3.1	1.9
	Average	4.7	2.7	3.2	1.6
Zahl	1	4.7	2.2	1.6	1.7
	2	2.8	1.0	1.8	0.8
	3	2.6	2.4	2.6	1.7
	6	4.4	1.4	1.9	0.9
	Average	3.6	1.8	2.0	1.3

Topo factors varied considerably with the distance the measurement was taken from a given site (Table 3). The Tonka soils would be expected to have a positive topo factor since they are located in depressional areas. Similarly the Bowbells soils located on footslope or toeslope positions would be expected to have positive topo factors. With one exception topo factors for Tonka soils were positive at all measuring distances. Bowbells soils had numerous negative topo factors measured at 3 and 6 m from the site. All topo factors measured at 15 to 30 m were positive for Bowbells soils. The Zahl soils would be expected to have all negative topo factors because of their location on hilltops and shoulders. Surprisingly, topo factors measured at a distance of 3 m were all positive in this field, while those measured at 15 m were all negative. The Williams soils which are located on backslopes should be intermediate between Bowbells and Zahl. Some of the topo factors for the Williams soils were positive and some were negative when measured 15 or 30 m from the site. Overall, topo factors measured at 15 m from the site seem to give the best values qualitatively matching their topographic position. Topo factors measured at 30 m were almost as good. Just why 15 m worked out best is not clear, but was probably related to the size of the topographic features in this landscape. A landscape with different topographic characteristics could produce optimum topo factors at other distances.

Table 3. Slope factors for slopes measured 3, 5, 15, and 30 meters from a site.

Soil series	Location	Distance from site (m) 3	5	15	30
	1	-0.30	-1.10	0.68	0.58
	2	-1.20	0.40	0.98	1.73
	3	2.50	-0.70	1.60	3.61
	4	4.90	0.20	0.80	1.28
	5	-0.60	-2.60	0.28	1.00
	6	3.40	1.05	2.26	2.97
Tonka	1	2.00	-0.50	1.06	1.99
	2	0.80	2.20	2.02	1.76
	3	5.20	5.20	6.08	5.94
	4	2.80	0.70	1.68	1.12
Williams	1	-1.00	0.55	1.90	1.46
	2	-0.30	-0.60	-1.38	-6.07
	3	-2.90	-4.10	-2.90	-3.96
	4	-1.00	-2.40	0.90	0.40
	5	-0.50	-1.05	-1.26	-1.56
	6	-1.80	-1.35	-0.65	-2.13
Zahl	1	1.10	-1.25	-0.92	-1.33
	2	0.30	-0.25	-3.20	-0.74
	3	0.30	-1.50	-1.58	-3.02
	4	3.20	-0.45	-2.22	0.69
	5	0.20	1.00	-4.02	-4.33
	6	0.30	-2.15	-2.08	-2.82

Topo factors measured at 15 m are given for the three fields at the Underwood location (Table 4) and the two fields at the Beulah location (Table 5). All of the values for Zahl were negative as expected and most of the Bowbells and all but one Tonka were positive.

The relationship between wheat yield and water use varied considerably and overall was only fair (Table 6). At Underwood the coefficient of determination (R^2) was 0.70 while the R^2 at Beulah in 1987 was only 0.04. The topo factor increased the R^2 values for both locations in all years when factored in to water use in the regression equations. For example, the R^2 from Underwood in 1985 increased from 0.70 to 0.80. The R^2 at Beulah in 1987 increased from 0.04 to 0.62.

The topo factored is intended to give a quantitative way to measure how water is redistributed in the landscape. The increases in R^2 with the addition of the topo factor into the regression equations indicates some success in quantifying the landscape effect. In most cases the increase in R^2 was greatest when topo factors were measured 15 m from the site. A distance of 15 m seems to be the optimum distance to measure slopes from a given site.

Table 4. Topo factors for the three fields at the Underwood location measured 15 m from the site.

Soil Series	Site	Field 1	Field 2	Field 3
Bowbells	1	0.68	-0.48	1.92
	2	0.98	-1.12	- 1.12
	3	1.60	-0.22	2.50
	4	0.80	0.98	0.78
	5	0.28	0.30	- 0.22
	6	2.26	0.96	1.00
Tonka	1	1.06	0.92	0.80
	2	2.02	3.92	- 0.82
	3	6.08	0.58	9.36
	4	1.68	1.06	5.02
Williams	1	1.90	1.32	- 1.18
	2	-1.38	-3.64	1.64
	3	-2.90	-3.96	- 0.38
	4	0.90	-1.38	- 7.80
	5	-1.26	-2.40	- 3.30
	6	-0.66	-1.98	- 1.70
	7			0.42
Zahl	1	-0.92	-7.36	- 7.44
	2	-3.20	-5.48	- 8.86
	3	-1.58	-4.82	- 5.48
	4	-2.22	-3.20	- 3.54
	5	-4.02	-5.22	- 5.60
	6	-2.08	-5.64	- 5.12
	7			-16.18

The percent change in water use at the highest R^2 value for a topo factor of ±1 varied from about 3 to 7% (Table 6). In other words, a topo factor of +1 would have increased the total water use at Underwood in 1987 by 7%; at Beulah in 1987 by 3%. It is assumed that the change in water available to the growing wheat plants came from runoff/runon phenomena or saturated and unsaturated flow of water in the soil profile downslope.

Table 5. Topo factors for the two fields at the Beulah location measured 15 m from the site.

Soil series	Site	Field 1	Field 2
Bowbells	1	1.40	2.54
	2	2.52	2.12
	3	1.50	2.52
	4	3.66	2.12
Williams	1	0.18	-1.18
	2	-0.54	3.76
	3	-0.44	-0.88
	4	0.20	-1.14
Zahl	1	-9.88	-4.68
	2	-3.34	-7.88
	3	-4.94	-3.34
	4	-1.66	-5.86
	5	-5.08	-7.10
	6	-6.60	

Table 6. Regression equations of the form yield = a(WU) +b where WU is water use.

Year	Location	a	b	R^2	%change in WU for a topo factor of ±1.0
			Unadjusted		
1985	Underwood	0.024	-1.49	0.70	0
	Beulah	-----	-----	----	-
1986	Underwood	0.013	-0.43	0.23	0
	Beulah	0.019	-1.08	0.62	0
1987	Underwood	0.007	-0.79	0.43	0
	Beulah	0.007	0.96	0.04	0
			Adjusted for Topo Factor		
1985	Underwood	0.017	-0.12	0.80	5
	Beulah	-----	-----	----	
1986	Underwood	0.015	-0.63	0.58	4
	Beulah	0.014	-0.13	0.68	3
1987	Underwood	0.005	-0.05	0.61	7
	Beulah	0.014	-0.62	0.62	3

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USE OF GLYPHOSATE AND INTERSEEDING TO IMPROVE SEASONALITY OF RECLAIMED GRASSLANDS

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ABSTRACT

In a seeded stand of native grasses, cool season grass species often predominate over warm season species. Field measurements were taken to evaluate the effect of treatments used to restore the seasonal balance of a seeded native grass stand dominated by cool season species. A reclaimed native grassland area, heavily dominated by pubescent and intermediate wheatgrass, contained only trace amounts of warm season grasses. Glyphosate (Roundup) was aerially skip-sprayed in perpendicular directions creating a checkerboard pattern of 0 (trace), 1½, and 3 pt/ac application rates. After the herbicide took effect, the area was burned and interseeded with a mixture of native warm season grasses. A portion of the original seeded area was retained as a control. Treatments applied had significant effects on the seasonal balance of the established stand. The proportion of warm season grasses increased on checkerboard blocks which received higher rates of glyphosate. Warm season species, including blue grama, sideoats grama and little bluestem replaced pubescent and intermediate wheatgrass. Areas treated with 3 pt/ac glyphosate had over 50% contribution of warm season species, compared to less than five percent on the control area. Total production, after three growing seasons, however, was reduced at higher herbicide rates. In summary, use of glyphosate followed by burning and interseeding can effectively increase the diversity and seasonal variety in an established seeded stand.

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INTRODUCTION

North Dakota Administrative Code 69-05.2-22-01 requires that reclaimed native grassland areas provide a diverse, effective, and permanent vegetative cover with seasonal variety, succession, and regenerative capabilities native to the area. The reestablishment of a seasonally balanced community is often difficult to achieve due to the competitiveness of cool season species (Williamson 1984). Early spring growth of cool season species makes them opportunistic, as they take advantage of moisture which is generally more available at that time. By the time temperatures and daylength are conducive to warm season growth, cool season species have developed to a vigorous growth stage. Since Federal and State regulations mandate seasonally balanced stands, it is necessary to look at management techniques aimed to help establish warm season grasses. Treatments to reduce weeds and cool season grass species competition have been used to stimulate warm season grass growth. Atrazine has been successfully used to reduce competition from aggressive species to aid in the establishment of warm season species (Martin et.al. 1982). Atrazine and glyphosate treatments were successfully applied to native grasslands to reduce cool season grass competition and stimulate warm season remnants (Waller and Schmidt 1983). Atrazine has also been used successfully to renovate seeded warm season pastures which have been overcome by smooth bromegrass (*Bromus inermis*) (Dill et.al. 1986). Grassland enhancement techniques which have been used successfully to improve seasonal characteristics on seeded grasslands include prescribed burning, application of non-selective herbicides and interseeding with warm season species (Nilson et.al. 1985). This paper discusses the use of glyphosate, used in conjunction with burning and interseeding treatments on a reclaimed grassland, to reestablish warm season species which were overcome by more aggressive cool season species.

STUDY AREA

The study area is located at the Glenharold Mine, approximately 50 miles (88 km) northwest of Bismarck, North Dakota. The site was mined in 1979 and reclaimed to native grassland in 1981. Prior to mining, the area was dominated by silty and shallow range sites. Low areas were occupied by claypan and thin claypan range sites. Dominant plant species included western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), needle and thread (*Stipa comata*) and threadleaf sedge (*Carex filifolia*). Premine soils consisted primarily of Amor (fine-loamy, mixed Typic Haploborolls) and Cabba (loamy, mixed (calcareous), frigid, shallow Typic Ustorthents) soils, with inclusions of Daglum (fine, montmorillonitic Typic Natriborolls) and Rhoades (fine, montmorillonitic Leptic Natriborolls) soils. The climate in this area is semi-arid, averaging 17 in (44 cm) precipitation a year. The majority of the precipitation occurs between April and July.

A 30 ac (12.2 ha) tract, located in portions of Sections 3 and 10, T143N, R84W, was reclaimed to native grassland. Soil was respread in April and May of 1981. Soil respread thickness was 15½ in topsoil (40 cm) and 33 in (84 cm) subsoil. The area was fertilized, seeded and mulched during the spring of 1981. Fertilizer, 11-45-0, was applied at a rate of 150 lb/ac (168 kg/ha). The area was seeded by late May, with the mixture shown in Table 1. Slough hay mulch was applied at a rate of 2 t/ac (4484 kg/ha).

By 1985, the area was heavily dominated by pubescent and intermediate wheatgrass (*Agropyron dasystachyum* and *Agropyron intermedium*). Warm season grass species were practically non-existent. A visual estimate determined that less than 5% relative cover was sideoats grama (*Bouteloua curtipendula*), the only warm season species contributing a substantial amount. The area had been hayed in a timely manner to improve seasonality characteristics; however, plant responses were minimal.

Table 1. Species and seeding rate for initial seeding of reclaimed native grassland in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

Species	Scientific Name	Season of growth	lb/ac PLS[1]	kg/ha PLS[1]
western wheatgrass	*Agropyron smithii*	cool	6.0	6.7
green needlegrass	*Stipa viridula*	cool	4.0	4.5
sideoats grama	*Bouteloua curtipendula*	warm	3.0	3.4
little bluestem	*Andropogon scoparius*	warm	2.0	2.2
pubescent wheatgrass	*Agropyron dasystachyum*	cool	1.5	1.7
yellow sweetclover	*Melilotus officinalis*	cool	1.0	1.1
alfalfa	*Medicago sativa*	cool	0.5	0.6
TOTAL			17.5	20.8

[1]PLS = Pure Live Seed

METHODS

In 1985, more drastic steps were taken to enhance species diversity and seasonality. The first treatment applied was an aerial spraying of glyphosate (Round-up), a non-selective herbicide on May 22. Ternate sections of spray nozzles were removed to create blocks of hit and miss treatments. The helicopter flew in a north-south direction, and then flew in an east-west direction, creating a "checkerboard" pattern of spray application. Spraying in this manner resulted in three herbicide treatments: 0 pt/ac (trace); half rate (single pass), 1½ pt/ac (1.75 l/ha); and full rate (double pass), 3 pt/ac (3.5 l/ha) (Figure 1). The 0 pt/ac rate (trace treatment) was the result of small amounts of glyphosate reaching plants because of drift. This was due to wind generated by the helicopter, even though special micro-drop nozzles were used. The second treatment was to burn the area so that interseeding could be accomplished. The entire tract was burned on June 19. On July 1 the area was interseeded with five warm season grass species and one cool season grass (green needlegrass) as shown in Table 2. Green needlegrass was added to the mix because of its sensitivity to glyphosate as demonstrated in other glyphosate trials at the Glenharold Mine. In subsequent years, the tract has been cut for hay.

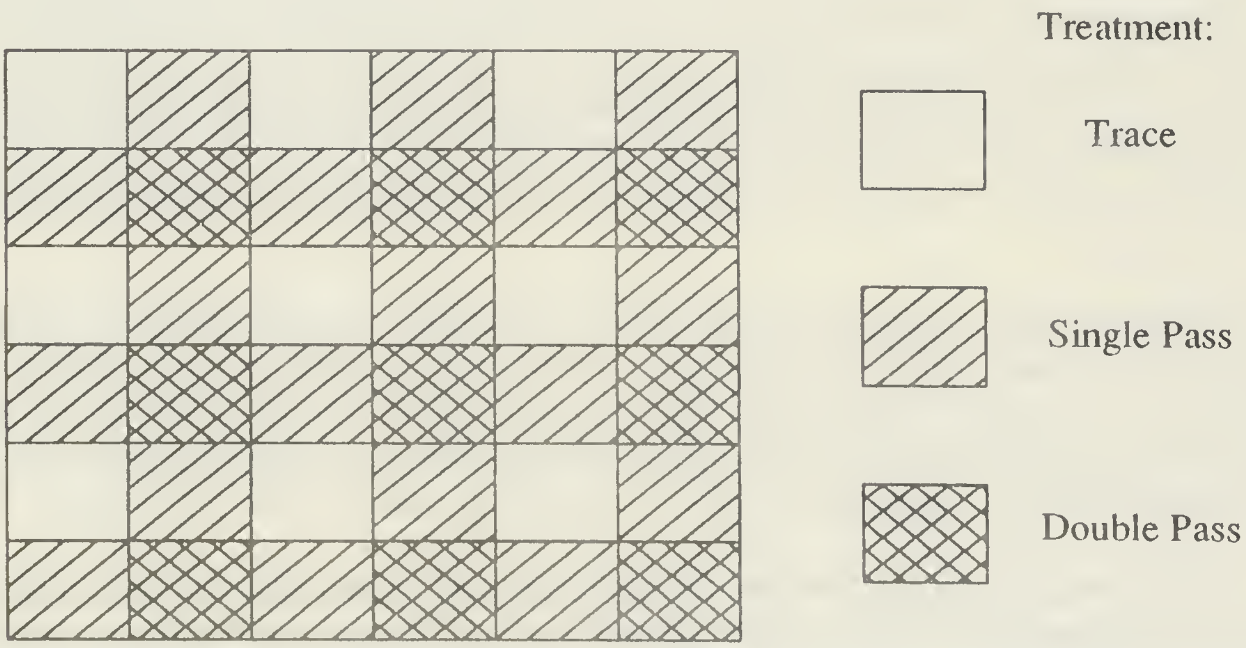

Figure 1. Herbicide treatments applied to reclaimed native grassland in Sections 3 and 10, T143N, R84W, at the Glenharold Mine in the spring of 1985.

Table 2. Species and seeding rate for interseeding treatment on reclaimed native grassland in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

Species	Scientific Name	Season of growth	lb/ac PLS[1]	kg/ha PLS[1]
blue grama	*Bouteloua gracilis*	warm	2.0	2.2
sideoats grama	*Bouteloua curtipendula*	warm	6.0	6.7
big bluestem	*Andropogon gerardii*	warm	3.0	3.4
sand bluestem	*Andropogon hallii*	warm	1.5	1.7
switch grass	*Panicum virgatum*	warm	2.0	2.2
green needlegrass	*Stipa viridula*	cool	3.0	3.4
TOTAL			17.5	19.6

[1]PLS = Pure Live Seed

To evaluate species composition, a 10-point frame was used to measure live basal cover (Cook and Bonham 1977). In 1986, 3000 points were randomly placed throughout the tract. Since data revealed equal proportions of warm and cool season species, the methods were modified in 1987 to determine the effects of the different spray treatments. A total of 2000 points were taken from each of the following areas:

Control:	no treatments to initial seeding,
Trace:	0 pt/ac rate glyphospate, burned, and interseeded
Single pass:	1½ pt/ac rate glyphospate, burned, and interseeded,
Double pass:	3 pt/ac rate glyphospate, burned, and interseeded.

Production data were collected from each of these treatments in 1987 at peak standing crop using a 0.25m^2 frame; 30 frames were sampled in each treatment. Sample size for cover and production measurements met all requirements of the North Dakota State Program, where the ratio of the standard error to the mean was <6%.

The 1987 data were analyzed using Least Significant Differences (LSD) with 95% confidence limits to test differences in treatment means (Snedecor and Cochran 1967). As used in this paper, pubescent wheatgrass includes small amounts of intermediate wheatgrass. Data for these two species were combined since identification between the two was often difficult, and since their ecological responses were expected to be similar.

RESULTS AND DISCUSSION

Treatments applied in 1985 had drastic effects on vegetation composition as early as 1986. The additional surface warmth created by the burning treatment, the timing of the interseeding, and timely rainfall, created an environment conducive to warm season species establishment. Warm season species comprised 44% of the relative basal cover (blue grama, 33%, and side-oats grama, 11%). The amount of pubescent wheatgrass, which predominated in 1985, was reduced to 18% relative basal cover. Annuals comprised 11% relative cover following burning and interseeding treatments.

Basal cover data from 1987 indicate how the different spray treatments affected species composition. Significant differences between treatment means, LSD tests, were detected between all treatments when looking at total warm season grasses (Table 3). Differences were not significant in the cool season group when comparing control vs. single pass, control vs. trace, and double pass vs. single pass treatments. Changes in the composition of cool and warm season species are shown in Figures 2 and 3, respectively. Significantly higher amounts of blue grama and sideoats grama were detected at the 95% confidence level between all treatments except treatment blocks that received only trace amounts of glyphosate. When comparing single pass vs. double pass treatments, significantly higher ($P < .05$)

amounts of blue grama occurred on the blocks that received 3 pts/ac while no difference in the amount of sideoats grama was detected. Significant differences between the control vs. single pass treatments combined with the lack of significance when compared to the trace application treatment indicate that the increase of these species was attributed to the use of the herbicide treatment, not just burning and interseeding. In other words, adequate suppression and elimination of wheatgrass plants using higher rates of glyphosate allowed the successful establishment of warm season species (primarily blue and sideoats grama). Other species present on single and double pass treatments after three growing seasons included big bluestem, sand bluestem, switchgrass and little bluestem.

Susceptibility of pubescent/intermediate wheatgrass and western wheatgrass varied between treatments. When compared to the control treatment, western wheatgrass had significantly higher live basal cover on all herbicide treatments. This species was most favorably affected by the single pass treatment which was sufficient to effectively reduce pubescent and intermediate wheatgrasses. As indicated by the results from the double pass treatment, western wheatgrass was susceptible to higher rates of glyphosate. Consequently, concentrations higher than 3 pt/ac would be necessary for more effective suppression or elimination of this species. The presence of higher amounts of sand bluestem, switchgrass and little bluestem in the double pass treatment is attributed to reduced competition from this species. Green needlegrass, which was interseeded with the warm season species, was not significantly affected by any treatments.

Table 3. Significance of treatment means of absolute basal cover by species using Least Significant Differences tests at the 95% level of confidence on reclaimed native grassland in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

	Treatment Comparisons[1]					
Species	C vs DP	C vs SP	C vs TR	DP vs SP	DP vs TR	SP vs TR
Western wheatgrass	+[2]	+	+	-[3]	-	+
Pubescent wheatgrass	+	+	-	-	+	+
Needle & thread[4]	-	-	-	-	-	-
Green needlegrass	-	-	-	-	-	-
Big bluestem	-	-	-	-	-	-
Sand bluestem	-	-	-	-	-	-
Blue grama	+	+	-	+	+	+
Sideoats grama	+	+	-	-	+	+
Switch grass	-	-	-	-	-	-
Little bluestem	+	-	-	-	+	-
Native forbs	-	-	-	-	-	-
Introduced Forbs	+	+	-	-	+	+
Annuals	-	-	+	-	+	-
<u>Species Groups</u>:						
Cool Season grasses	+	-	-	-	+	+
Warm Season grasses	+	+	+	+	+	+

[1]C = Control; DP = Double Pass; SP = Single Pass; TR = Trace
[2]Significant
[3]Not Significant
[4]*Stipa comata*

Total production was reduced significantly by the single pass and double pass herbicide treatments (Table 4). The trace treatment was the most productive, yielding 3129 lb/ac (3507 kg/ha). Reduction in yield was primarily related to reduced forb production (Figure 4). Alfalfa and sweetclover were reduced severely by the single pass and double pass treatments. No significant reduction in forbs was detected with the increased herbicide rate in the double pass treatment as compared to single pass. Grass production increased significantly in all treatments compared to the control. Total grass yield in the control plot was 1272 lb/ac (1426 kg/ha), as compared to double pass with 1665 lb/ac (1866 kg/ha), single pass with 1549 lb/ac (1736 kg/ha) and trace with 1447 lb/ac (1621 kg/ha). In the case of reclaimed native grassland, the abundance of species such as alfalfa and sweetclover is not necessarily desirable since they

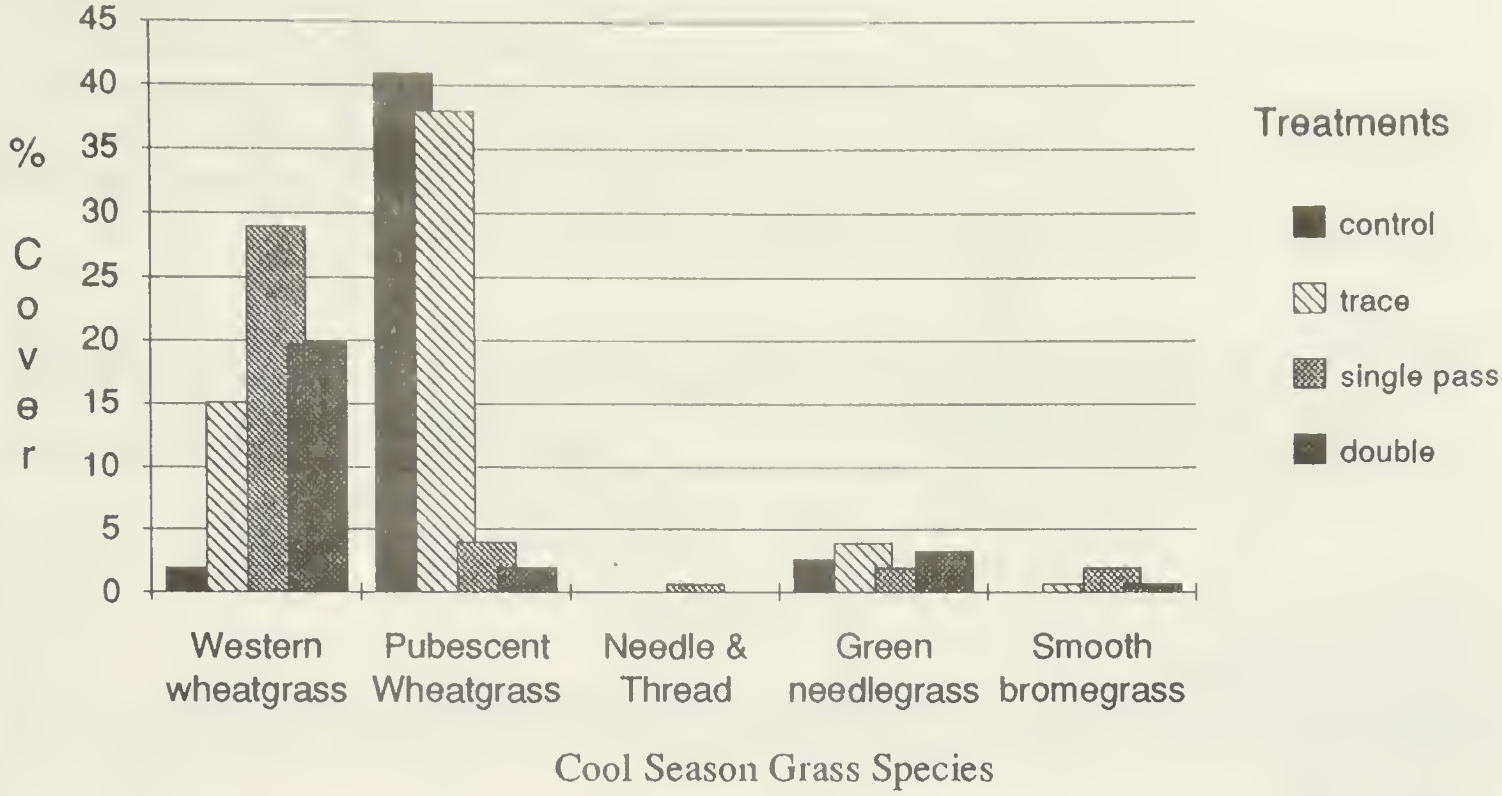

Figure 2. Percent relative basal cover of cool season grass species on reclaimed native grassland treated with glyphosate, burned and interseeded to improve seasonal variety, in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

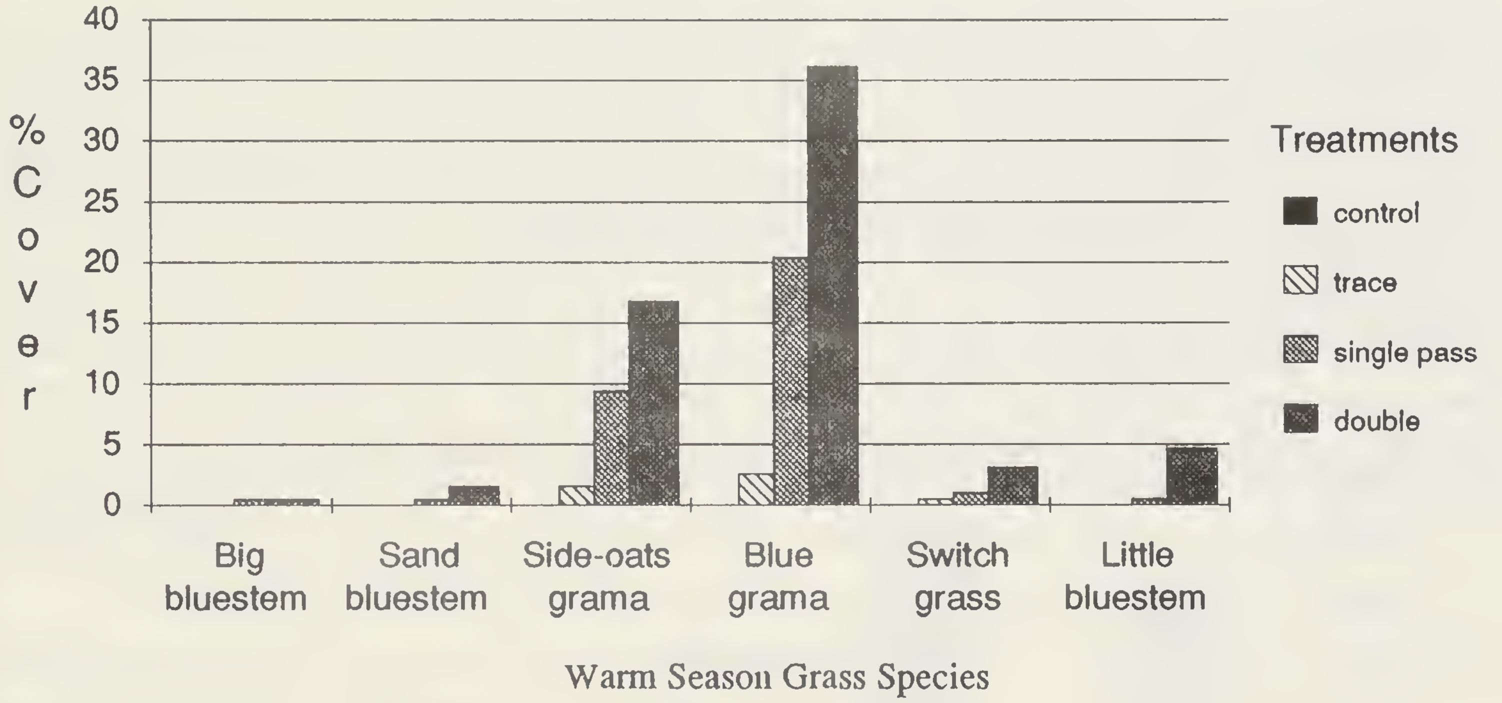

Figure 3. Percent relative basal cover of warm season grass species on reclaimed native grassland treated with glyphosate, burned and interseeded to improve seasonal variety, in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

are not sustained under prolonged or inappropriate grazing. Although these species are more productive, they are generally associated with tame grassland or hayland mixes. Therefore, it is important to note the increase in production contributed by native grass species rather than by introduced forb species.

Warm season grasses increased significantly at higher herbicide rates. Significant differences, in the proportion of warm season grasses, were detected between all treatment comparisons, except control vs. trace (Table 4). This reflects the importance of the herbicide treatments in augmenting the effects of

burning and interseeding treatments. Changes in grass species and groups are shown in Figure 5. Similar to cover data, production of western wheatgrass increased significantly in all treatments when compared to control. Conversely, pubescent wheatgrass production declined significantly ($P<.05$) in the single pass and double pass treatments. Suppression and elimination of this species allowed for an increase in cover and production of western wheatgrass as well as in all interseeded warm season species, except switchgrass. After three growing seasons, blue grama and sideoats grama became the predominate warm season species, contributing to significantly higher total grass production.

Table 4. Significance of treatment production means by species using Least Significant Differences tests at the 95% level of confidence on reclaimed native grassland in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

	Treatment Comparisons[1]					
Species	C vs DP	C vs SP	C vs TR	DP vs SP	DP vs TR	SP vs TR
Western wheatgrass	+[2]	+	+	+	+	+
Pubescent wheatgrass	+	+	-[3]	-	+	+
Green needlegrass	+	+	+	+	-	-
Big bluestem	+	+	-	+	+	+
Little bluestem	+	+	-	+	+	+
Blue grama	+	+	+	+	+	+
Side-oats grama	+	+	+	-	+	+
Switch grass	-	-	-	-	+	+
Sand dropseed[4]	-	-	-	+	+	-
Native forbs	-	-	-	-	-	-
Introduced Forbs	+	+	-	-	+	+
Annuals	-	-	-	-	-	-
<u>Species Groups</u>:						
Total production	+	+	+	-	+	+
Total grass production	+	+	+	-	+	-
Cool Season grasses	+	+	+	+	+	+
Warm Season grasses	+	+	-	+	+	+

[1]C = Control; DP = Double Pass; SP = Single Pass; TR = Trace
[2]Significant
[3]Not Significant
[4]*Sporobolus cryptandrus*

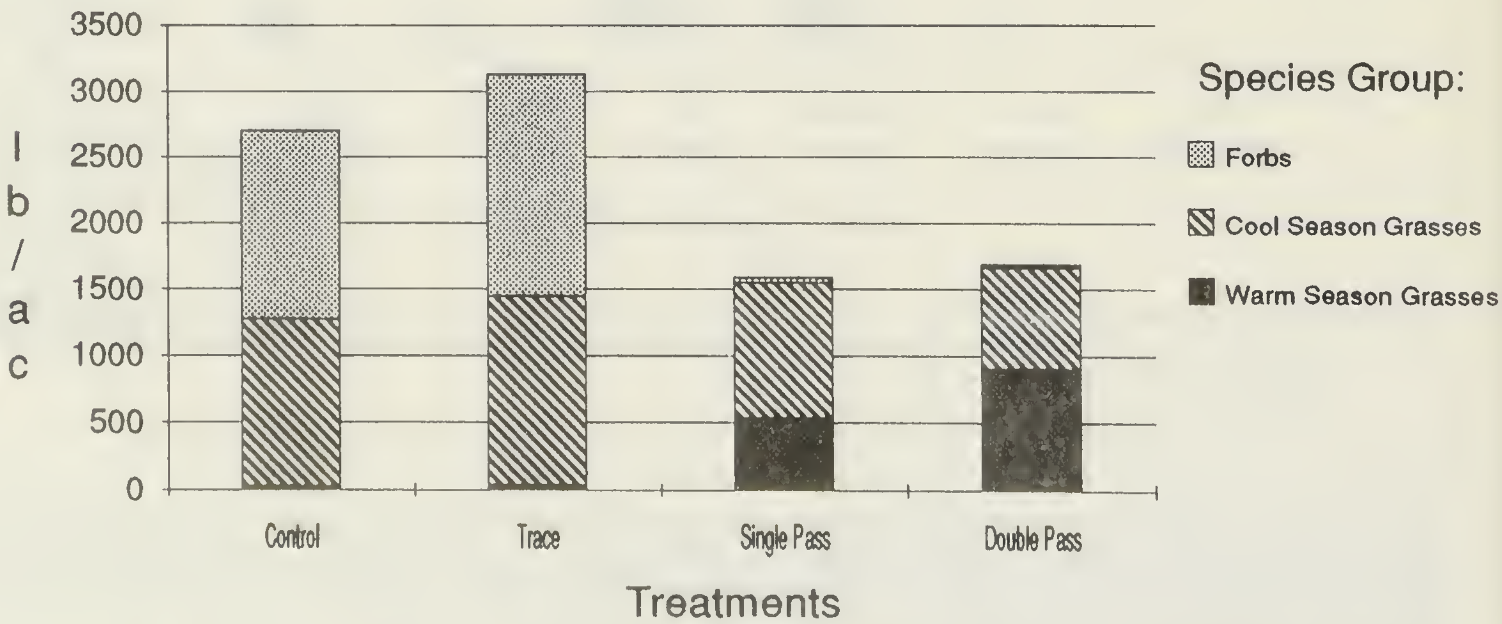

Figure 4. Total production (lb/ac) of reclaimed native grassland treated with glyphosate, burned and interseeded to improve seasonal variety, in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

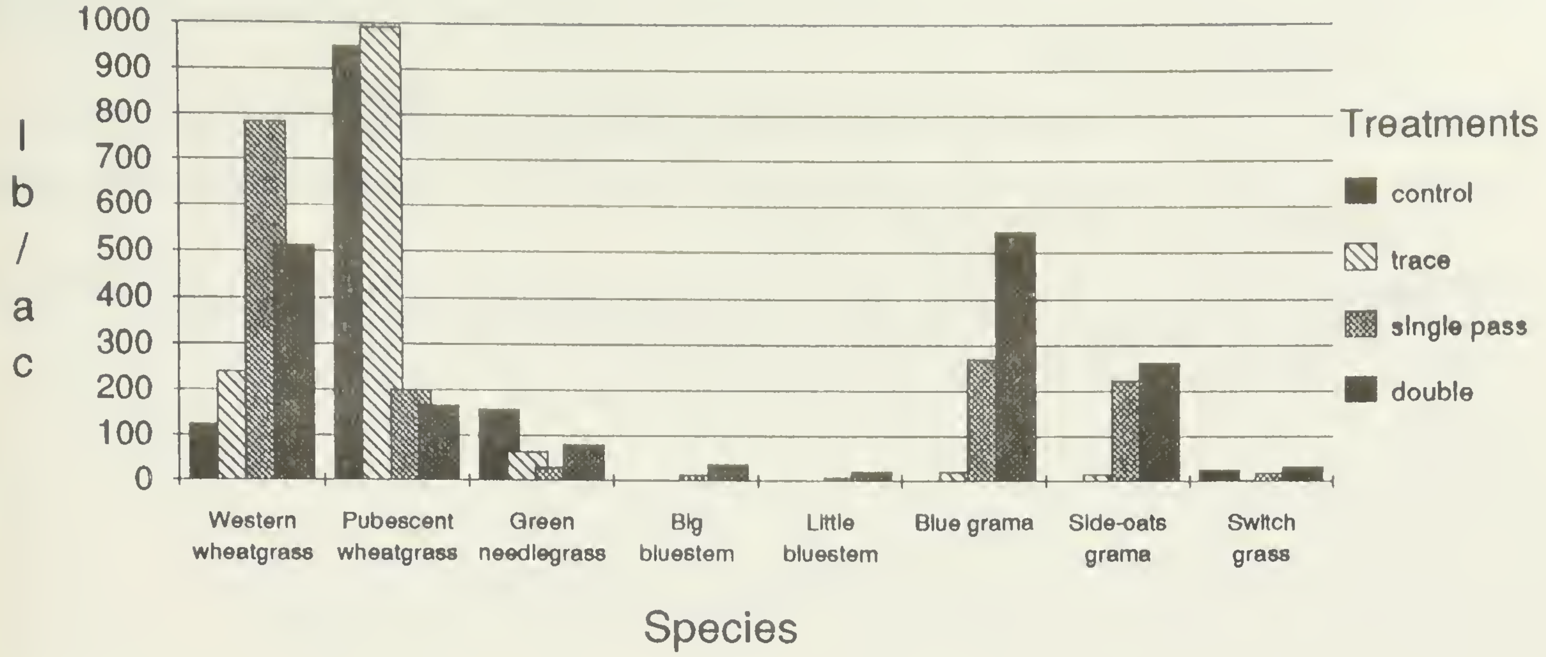

Figure 5. Total production (lb/ac) of reclaimed native grassland treated with glyphosate, burned and interseeded to improve seasonal variety, in Sections 3 and 10, T143N, R84W, at the Glenharold Mine.

SUMMARY

Glyphosate, burning and interseeding treatments successfully suppressed dominant cool season species and promoted warm season grass establishment. Dramatic changes in the proportions of warm season grasses occurred the first year after treatment application. Burning followed by interseeding with minimal cool season suppression (trace treatment), was not successful in increasing warm season grass distribution and abundance. This emphasizes the futility of simply overseeding a stand which is deficient in diversity and seasonal variety. Use of glyphosate treatments in a trace/half-rate/full-rate checkerboard pattern was effective in reducing competitive species without a detrimental effect on grass production. Excluding forbs, total grass production increased with higher rates of glyphosate; concurrently, higher cover and production values of interseeded warm season species were observed on blocks that were treated with 1½ and 3 pt/ac rates. Herbicide treatments have been used to stimulate warm season growth if warm season species are present in the stand. However, interseeding warm season species is necessary if their distribution and abundance are insufficient to effect a positive response with management practices.

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PONDEROSA PINE RECLAMATION AT THE ROSEBUD MINE

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ABSTRACT

The first operational plantings of ponderosa pine (Pinus ponderosa) were made on the Rosebud Mine near Colstrip, Montana in November of 1985. This paper discusses the five "R's" of pine reclamation. These include the **Reasons** for planting ponderosa pine, ponderosa pine **Research** efforts and results, present **Reclamation** methods and materials, the **Results** of pine reclamation to date and the relationship of these results to the final bond **Release** criteria.

Over 14,000 pine seedings have been planted to date. They have been 1-0 to 3-0 bare root or 1-0 to 2-0 containerized stock. Plantings have been done by hand, with augers and (primarily) with a modified Soil Conservation Service tree planter on "tree" and regular soils with and without animal damage protection in spring and fall. Percent survival has varied greatly from field to field influenced by record drought, wildfire, severe grasshopper depredation, cattle grazing and wildlife usage.

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INTRODUCTION

Ponderosa pine (Pinus ponderosa) is native to the Colstrip area. Pfister, et.al (1977) described various Pinus ponderosa series occurring in eastern Montana including pine savannas. Pine was found in all pre-mine vegetation surveys conducted at the Rosebud Mine for Western Energy Company with densities ranging from 18 per acre in Area "A" to 97 per acre in Area "E" (Culwell, 1988). A maximum of 2272 acres of pine habitat may be disturbed by the Rosebud Mine (Table 1).

Table 1. Ponderosa pine acres permitted at the Rosebud Mine, Colstrip, Montana

Area	Revegetation	Disturbance	Permit
A	463	445	A-Existing and A-Extension
B	121	119	B-Existing and B-Extension
C	662	685	C-Amendment
D	958	975	D-West (pending approval)
E	62	48	E-Admendment (pending approval)
Total	2266	2272	

REASONS

One reason to reclaim pine habitat is to fulfill the requirements of law and obtain final bond release. Section 82-4-2333 of the Strip and Underground Mine Reclamation Act as amended in 1985 states, "(1)....the operator shall....plant....trees as are necessary to establish....a diverse, effective and permanent vegetative cover....native to the area....at least equal in extent of cover to the natural vegetation of the area....:

(a) feeding....a quantity and mixture of wildlife and livestock at least comparable to that....sustained prior to the operator;

(b) regenerating under natural conditions....; and

(c) preventing soil erosion to the extent achieved prior to the operation."

Wildlife occurence in the ponderosa pine habitat type throughout southeastern Montana has been well documented (Knapp, 1972; Martin, 1980; Martin et.al., 1981). It is important to mule deer year-around for escape and thermal cover. It is also utilized for cover and forage by game

bird and non-game species in the immediate Colstrip vicinity (ECON, 1973; ECON, 1974). Wildlife usage is the primary reason behind the requirement for ponderosa pine habitat type reclamation. If livestock production was the only goal of reclamation, grasslands would be the only habitat type replanted.

RESEARCH

Ponderosa pine research was conducted at the Rosebud Mine by the University of Montana's School of Forestry from 1979 through 1987. Seven graduate theses (Richardson, 1981; Woods, 1982; Vance, 1983; Baumbuaer, 1984; Riley, 1984; Danielson, 1986; Thamarus, 1987) and six publications (Woods and Blake, 1981; Woods et.al, 1983; Baumbauer and Blake, 1984; Woods et.al, 1984; Vance and Running, 1985; Thamarus and Blake, 1987) resulted from this research. Two major reports to Western Energy Company, "Studies of the Ecology of *Pinus Ponderosa* at Colstrip: (Stark, 1985) and "A Guide for the Establishment of Ponderosa Pine on the Rosebud Mine, Colstrip, Montana" (Blake and Running, 1986) summarize most of this research effort and information.

Two of the more important research discoveries were that inheritance of some form of drought resistance takes place (Riley, 1984) along with identification of specific pine trees with superior survival qualities and documentation of extensive root development unimpeded by planting technique, material usage or reconstituted minesoils (Thamarus, 1987).

RECLAMATION

Most of the 14,721 pines planted were grown from seeds gathered in the Colstrip vicinity from trees identified during the research effort. The only exception was the Spring 1986 bareroot stock (Table 2) which came from a seed source on the Missouri River north of Jordan, Montana.

Ponderosa pine seedlings have been planted in handmade holes and holes drilled by power augers. The majority of the seedlings have been planted with a modified Soil Conservation Service three-point planter pulled by a 100 horsepower tractor. This method was first used extensively to plant 23,000 acres of pine trees on the McKelvie National Forest in the sand hills country of Nebraska (Hunt, 1965).

Western Energy Company has planted 1-0 and 3-0 bare root and 1-0 containerized stock into single lift "tree"

soils and double lift soils in 18 different locations. It has been planted with the "uplands" grass mix as well as the "conifer" mix. It has been planted in newly seeded fields and fields where grasses were firmly established. The pine trees have been subjected to wildlife depredation, drought, wildfire and grasshopper damage. A few have been damaged by livestock. Some plants were protected from mammal depredation with Vexar plastic tubing. A few were given shade protection with shade cards and some were given moisture loss protection with Terra-Mats®. Some were sprayed with simazine to reduce competion from grass and forb species. Some were hand watered from a tractor-drawn tank.

Table 2. Pine plantings by Western Energy Company of Colstrip

Method	Season	Year	Age	Type[1/]	Number
Treeplanter/hand	Fall	1985	1-0	B	1,124
Treeplanter/auger	Fall	1985	1-0	C	1,800
Treeplanter	Spring	1986	3-0	B	2,968
Treeplanter	Fall	1986	1-0	C	1,100
Treeplanter	Fall	1987	1-0	C	2,254
Treeplanter	Spring	1988	1-0	C	2,094
Treeplanter	Fall	1988	1-0	C	1,078
Treeplanter	Spring	1989	1-0	C	1,078
Treeplanter	Fall	1989	1-0	C	1,225
Total					14,721

[1/] B-Bare root; C-Containerized

Western Energy Company believes planting 1-0 containerized pine seedlings grown from locally gathered seed, with the treeplanter at a rate of approximately 110 per hour, into shallow soil (or subsoil) newly seeded with the "conifer" mix, followed by an application of simazine the following spring and cattle grazing two to three years after planting to be the most cost effective, practical method of establishing pine trees on reclaimed land.

RESULTS

As might be expected from the number of variables listed above, the survival rates vary greatly from field to field ranging from 0 to 100%. With our limited number of transects and total count data (Table 3) as qualifiers, the following general statements can be made:

Table 3. Ponderosa Pine Survival

	Original Planting				June 1989 Survival		
Field	Acres	Total	Date	Density (No. Per Acre)	Total	Percent	Density (No. Per Acre)
Area A-3852	2.5	1176	11/87	470	25	2***	10
2871	0.9	496	3/88	551	20	4***	22
4881	2.4	294	11/88	123	294	100*	123
4882	1.3	196	11/88	151	159	81*	122
4884	3.0	588	11/88	196			
		1078	4/89	359			
		1666		555	1568	94*	523
2898	2.8	441	10/89	158	441	100***	158
Area C-3851		1200	11/85	600	84	7*	42
		600	11/85	300	60	10*	30
	2.0	1800		900	144	8*	72
4852	2.5	468	4/86	187	117	25**	47
1861	2.4	1500	3/88	625	0	0*	0
1882	1.6	98	3/88	61	0	0*	0
4891	5.4	784	10/89	145	784	100***	145
Area D-3871	2.6	392	11/87	151	157	40*	60
Area E-3852	3.0	824	11/85	275	0	0*	0
3851	3.0	300	11/85	100	100	33*	33
2851	6.6	1900	4/86	288	380	20*	58
1861		600	4/86	143	528	88*	126
		1100	10/86	262	275	25*	65
	4.2	1700		405	803	47	191
2861	0.5	196	11/87	392	0	0**	0
4821/2831	1.8	490	11/87	272	49	10*	27

Field	Suggested Standard[2]	Acres	Total	Density (No. Per Acre)	Total	Percent	Density (No. Per Acre)
Area A	18	12.9	4269	331	2507	59	194
Area C	32	13.9	4650	335	1045	22	75
Area D	65	2.6	392	151	157	40	60
Area E	97	19.1	5410	283	1332	25	70
Total		48.5	14,721	304	5041	34	104

* Transect estimation ** Total count *** Visual estimation [1] Culwell, 1988

1. The highest mortality rates of trees planted on slopes occur near the top of the slope. Trees on the bottom two rows had a 54% survival rate in field C-4852 (Table 4).

2. The highest mortality occurs during the first year after planting. Trees in field C-4852 had a 94% survival rate after the first year during which 74% died.

Table 4. Field C-4852 Pine Survival Data

		Survey Date			Total Mortality (%)
Slope	Row	April 1986	June 1987	October 1989	
Top	1	151	9	8	94.7
	2	124	21	16	87.1
	3	89	37	37	58.4
	4	67	37	36	46.3
Bottom	5	37	20	20	45.9
Total		468	124	117	75.0
Density (#/acre)		187.2	49.6	46.8	
Survival (%)-		--	26.5	25.0	
			--	94.4	

3. Trees planted into existing grasslands have very low survival rates (C-1861 0%, A-3852 1%; E-2831 10%).

4. The drought of 1988 was especially hard on the young trees. There were seven plantings in Fall 1987 and Spring 1988 with a combined survival rate of 6%. Three of these fields, which were planted in association with the upland grass mixture, were total losses.

5. The difference in affect of the upland verses conifer grass mixture is also shown in fields E-2851 and E-1861. The upland field has 20% pine survival compared to 88% survival in the conifer field. Grasshopper depredation on the moisture stressed trees in field E-2851 was very evident during the summer of 1987.

6. Shade card, Terra-Mat® and Vexar tubing applications had no noticable effects on survival rates.

7. The soil type was not a major factor in pine survival with F3 (tree soils) having a range of 0 to 81% survival and F1/F2 (double lift soils) having a range of 0 to 100% survival.

RELEASE

The Montana Department of State Lands has issued permits for Western Energy to plant 2,266 acres of pine trees at the Rosebud Mine (Table 1) at a minimum density of 100 trees per acre. So far we have planted 48.5 acres at 304 trees per acre. It would seem we are greatly exceeding the density requirement. The question is, "Is it enough?"

Saving the dilemma of reducing competition from grasses and controlling erosion while pines are becoming established and still meeting the ground cover requirements for another forum, Western Energy needs to know what, if any, stocking rate is acceptable to start the bond release clock.

There are two ponderosa pine reference areas (Coenenberg 1983) with measured densities of 253 and 1216 trees per hectare respectively. Their average density is 734 trees per hectare with a standard deviation of ± 681 (297 ± 275/acre). The minimum acceptable stocking rate would seem to be 53 trees per hectare or 22 trees per acre. With this figure as our goal we currently have five fields (10.0 acres) which would not qualify. Two others (3.6 acres) are in jeopardy of dropping below the minimum stocking rate level. Western Energy has 38.5 acres which would meet the minimum rate. No acres would meet the average density of 297 trees per acre. Culwell (1989) found the density of the same two reference areas to be 220 ponderosa pine per acre. He suggested standards to judge reclamation densities that range from 18 stems per acre in Area A to 97 stems per acre in Area E base on pre-mine densities (Culwell, 1988). Some more questions are "what exact densities will be required for final bond release? Will they apply to each individual field or be averaged by area?"

Individually, only half (9) of the fields would qualify for bond release at the suggested stocking levels. A further examination of five planting variables (Table 4) as they relate to bond release shows that soil type and season of planting don't have much effect on survival rates. The seed mix planted in association with the pines seems to be significantly related to survival. The most evident difference (pass vs fail) occurs in the "time" category with the youngest age class fields having the best passing ratio.

The administrative rules of Montana spell out the current requirements for determining reclamation success and resulting bond release for trees and shrubs, including Ponderosa pine. The stocking rate, i.e. the number of

stems per unit area, will be the determining statistic (section 26.4.733). This stocking rate (density) must be comparable to the density of the same life form (i.e. pine trees) on approved reference areas with an 80% statistical confidence level. Furthermore the area must meet acceptable ground cover requirements **before** the ten year responsibility period begins (section 26.4.735). What is the status of our ponderosa pine? Is the bond release clock running? Has it ever started?

Table 4. A comparison of five ponderosa pine planting variables by relationship to suggested final bond release survival densities.

Variable	Type	Total Fields	Pass[1/] No.	Pass[1/] %	Fail[2/] No.	Fail[2/] %
Time	Post-summer 1988	5	5	100	0	0
	Pre-summer 1988	13	4	31	9	69
Season	Spring	6	3	50	3	50
	Fall	12	6	50	6	50
Seed mix	Conifer	9	6	67	3	33
	Upland	9	3	33	6	67
Soil	F1/F2	13	7	54	6	46
	F3	5	2	40	3	60
Seedling	Container	13.5	7.5	56	6	44
	Bare root	4.5	1.5	33	3	67

[1/] Meet or exceed suggested stocking rate by field by area (Culwell, 1988).
[2/] Stocking rate below minimum suggested level.

Another problem lies in determining the area to be considered as "pine reclamation". The reclamation densities are based on a polygon drawn around the original planting site. If the polygon were reduced in size to reflect observed mortality, the stocking rate would rise correspondingly. If the polygon is enlarged in a field which has experienced a high survival rate, the stocking rate will decrease but could still remain significantly above the critical minimum level. Will the company be forced to replant trees into originally planted areas knowing that they will suffer an extremely high mortality rate and increase erosion potential? Will we be forced to plant trees according to an outdated revegetation plan or will we be able to plant them in the best available locations each spring and fall in an opportunistic manner until the extent and density requirements are fulfilled?

SUMMARY

Our research and practical experience in the realm of large scale ponderosa pine planting have shown that pines can be an integral part of the reclamation picture.

They can be established on reclaimed lands and will survive the hardships of nature, including drought and animal depredation, in great enough numbers to meet minimum bond release requirements. The flexibility to take advantage of the best planting situation must be part of the system. And finally, reclamation must not be confused with restoration as restoration of the original extent and density of pine habitat, would require at least triple our present substantial effort and expense.

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Billings Symposium, 1990

BORON TOXICITY OF COAL MINING AREAS IN SOUTHWESTERN WYOMING

R.L. Hanson[1], P.W. Smith[2] and J.A. Smith[3]

ABSTRACT

Boron tolerance of native plant species is not generally known. This study was conducted to determine the B tolerance of thickspike wheatgrass [Agropyron dasystachyum (Hook.) Scribn.], a species commonly used to reclaim minelands in the semiarid and arid West. Pre-germinated thickspike wheatgrass seeds were planted in three soil materials obtained from a coal mine in southwestern Wyoming. Soils were taken from an undisturbed bottomland (clay), a topsoil stockpile (sand), and a carbonaceous shale outcrop (shale) with inherent hot water extractable-B (HWE-B) levels of 2.8, 1.3, and 3.5 mg/kg soil, respectively. Each soil material was treated with boric acid solutions to produce seven different HWE-B levels. B levels ranged from inherent conditions up to 57.9 mg/kg. Plants were grown under greenhouse conditions for 100 days in pots containing 2.9 kg of clay or shale or 3.4 kg sand. Wheatgrass shoot and root dry matter production were measured. Toxicity symptoms (leaf tip necrosis) were observed in all treatments but the controls during the study. Levels of 11.6 and 20.5 mg/kg HWE-B produced an average of 10 and 20% reductions in shoot production, respectively. Ten and 20% reductions in root growth were observed with 3.8 and 6.6 mg/kg HWE-B, respectively. Plants grown in the sand were most B sensitive. This is postulated to be a result of the drier conditions attendant in that soil. Results indicate that thickspike wheatgrass can tolerate HWE-B levels in excess of 5 mg/kg. However, actual field tolerance levels will be dependent on climatic and soil environmental conditions, particularly moisture availability.

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INTRODUCTION

Boron is an element that is essential to plant growth but can also be toxic to plants at relatively low concentrations (Keren and Bingham, 1985). Boron concentration in soils is largely dependent upon climate and parent material. Soils formed under limited leaching conditions of the arid and semiarid West often exhibit elevated B levels (Aubert and Pinta, 1977). Parent materials containing carbonaceous shales and coal lenses which consist of biologically inert organic matter high in B (Power et al., 1978) can also result in boroniferous soils. Climate and geologic settings of this type are typical of the coal producing area of southwestern Wyoming.

Soils containing greater than 5 mg/kg hot water extractable-B (HWE-B) have generally been considered unsuitable as a growth medium for agronomic crops (Reisenauer et al., 1973). Solution B concentrations in excess of 5 mg/kg have also been found to inhibit the growth of numerous agricultural crop and turfgrass species (Oertli et al., 1961). Presently, most western coal mines are required to use field crop B tolerance criteria to reconstruct soils. A 5 mg/kg HWE-B level has been adopted by the Wyoming Department of Environmental Quality as a suitability criteria for soil reconstruction. However, it has been hypothesized that native species adapted to dry climatic conditions may be able to tolerate higher B levels than field crops. Smith and Lindsay (1982) found that 7.2 to 10.2 mg/kg of 1M ammonium acetate extractable B in retorted oil shale reduced 'Rosanna' western wheatgrass (*Agropyron smithii* Rydb.), tall wheatgrass [*Agropyron elongatum* (Host) Beauv.] and alkali sacaton [*Sporobolus airoides* (Torr.) Torr.] yields by 10%. Shoot production of tall wheatgrass was reduced by 50% when grown in a treated soil with 46 mg/kg saturation paste extractable B (Schuman, 1969a). Roundy (1985) noted that shoot production of 'Jose' tall wheatgrass was reduced by 50% at 66 mg/kg when grown in a sandy loam soil that was irrigated with solutions containing B.

Although B levels obtained from different extractants cannot directly compared, this literature supports the hypothesis that plants native to arid environments are relatively B tolerant. The objective of this study was to determine the soil B tolerance limits of thickspike wheatgrass when grown in three different boric acid pretreated soil materials native to the semiarid environment of southwestern Wyoming.

METHODS AND MATERIALS

Twelve pre-germinated thickspike wheatgrass seeds were planted in plastic lined one gallon cans, containing one of three soils collected from a coal mine located in southwestern Wyoming. The soil materials were a sandy loam obtained from a topsoil stockpile containing a mixture of several different soils, a clay obtained from the upper 15 cm of an undisturbed bottomland soil (Terreton fine, montmorillonitic (calcareous), fridid Typic

Torriorthent) and a carbonaceous shale obtained from an outcrop of the Upper Cretaceous Lance Geologic Formation. Soils are referred to as sand, clay, and shale, respectively. The chemical parameters for each soil are listed in Table 1. Seven B treatment levels were applied to soils by sprinkling boric acid solutions onto continuously mixed soil employing a modification of the methods used by Hatcher et al. (1962). Table 2 lists the amount of B added to each soil prior to planting and the HWE-B (Bingham, 1982) from each soil at the end of the study. The B treatments were replicated three times for each soil material in a completely randomized experimental design.

During establishment of the germinated seeds, the soil surface of each pot was kept moist by adding 100 ml of distilled water for 12 consecutive days. After seedling establishment, each pot was watered with distilled water to field capacity on two week intervals. Pots were thinned to leave eight average sized plants after 38 days. No thinning was performed in pots with less than 8 plants. Plants were grown in a greenhouse with minimum and maximum air temperatures throughout the duration of the study ranging from 9 to 41° C. Mercury vapor lights were used to provide a day length of 16 hours to simulate growing season conditions. Average plant height and length of leaf tip necrosis [a symptom of B toxicity, (USDA, 1960)] were measured. These measurements were initiated 24 and 52 days after planting, respectively. Subsequent measurements were taken at two and three week intervals until the end of the study. All aboveground biomass was harvested after 100 days, dried at 60°C and weighed. Root biomass was determined by washing roots from a single pot for each treatment using pots with similar plant numbers. Multiple regression analysis was used to analyze data. Percent yield reduction of root and shoot biomass was estimated using the regression models.

RESULTS AND DISCUSSION

Mean seedling survival measured 38 days after planting (prior to thinning) is shown in Table 3. Seedling survival

Table 1. Chemical characteristics of the soils used in study.

SOIL	HWE-B	Ca	Mg	Na	K	pH	EC	TEXTURE CLASS
		----- SOLUBLE CATIONS -----						
	------------- mg/kg ------------						dS/m	
Sand	1.3	132.0	29.1	219.0	20.9	7.6	1.9	SL
Clay	2.8	53.1	14.6	98.4	1110.0	8.1	0.9	C
Shale	3.5	710.0	572.0	149.0	27.7	6.4	5.6	SL

decreased with increasing B level in each soil material studied. However, the greatest seedling mortality was observed in treatments with greater than 50 mg/kg HWE-B. In these pots, 6 or fewer out of the 12 pre-germinated seeds planted actually grew. All other treatments had an average of at least 8 surviving plants.

Boron toxicity symptoms (leaf tip necrosis) were first observed 24 days after planting. These symptoms were observed at B treatment levels of 17.7, 20.8, and 25.2 mg/kg HWE-B for the sand, clay, and shale, respectively. After 38 days, symptoms were apparent in plants grown at 12.2, 18.5, and 17.7 mg/kg HWE-B in the sand, clay, and shale, respectively. Subsequent B toxicity symptom observations were quantified by measuring the length of necrosis on the youngest fully expanded leaves (Table 3). Three trends were evident from these data. First, plants grown in sand at lower HWE-B treatments (less than 10 mg/kg) exhibited more severe toxicity symptoms than plants grown in the other soils with similar HWE-B levels. Second, in most cases necrosis length increased as HWE-B increased. However, anomalies to this observation did occur. Less necrosis was observed in some of the highest B treatment levels compared to lower levels. This can be partially explained by reduced growth of plants (see height data, Table 3) in the highest HWE-B treatments. Third, necrosis of the youngest fully expanded leaf decreased as the plant matured beyond 65 days in the clay and shale. Oertli et al. (1961) and Schuman (1969a) obtained similar results with alta fescue (*Festuca arundinacea* Schreber) and tall wheatgrass, respectively. These researchers suggested that dead leaf tissue may act as a sink for B thereby reducing accumulation of B in new leaves. A similar progressive leaf necrosis was observed during this study.

Average thickspike wheatgrass heights are shown in Table 3. Height measurements and visual observations showed an inverse

Table 2. Concentrations of added and hot water extractable B relative to target levels.

TARGET HWE-B	SAND ADDED	SAND HWE-B	CLAY ADDED	CLAY HWE-B	SHALE ADDED	SHALE HWE-B
			mg/kg			
CONTROL	0	1.3	0	2.8	0	3.5
5	6.8	4.6	5.0	4.7	1.8	4.3
10	15.9	8.6	11.6	9.1	8.3	9.6
15	25.0	12.2	18.1	13.0	14.8	17.7
20	34.1	17.7	24.7	18.5	21.3	19.2
25	43.2	25.3	31.3	20.8	27.8	25.2
40	70.4	53.7	51.0	29.1	47.3	57.9

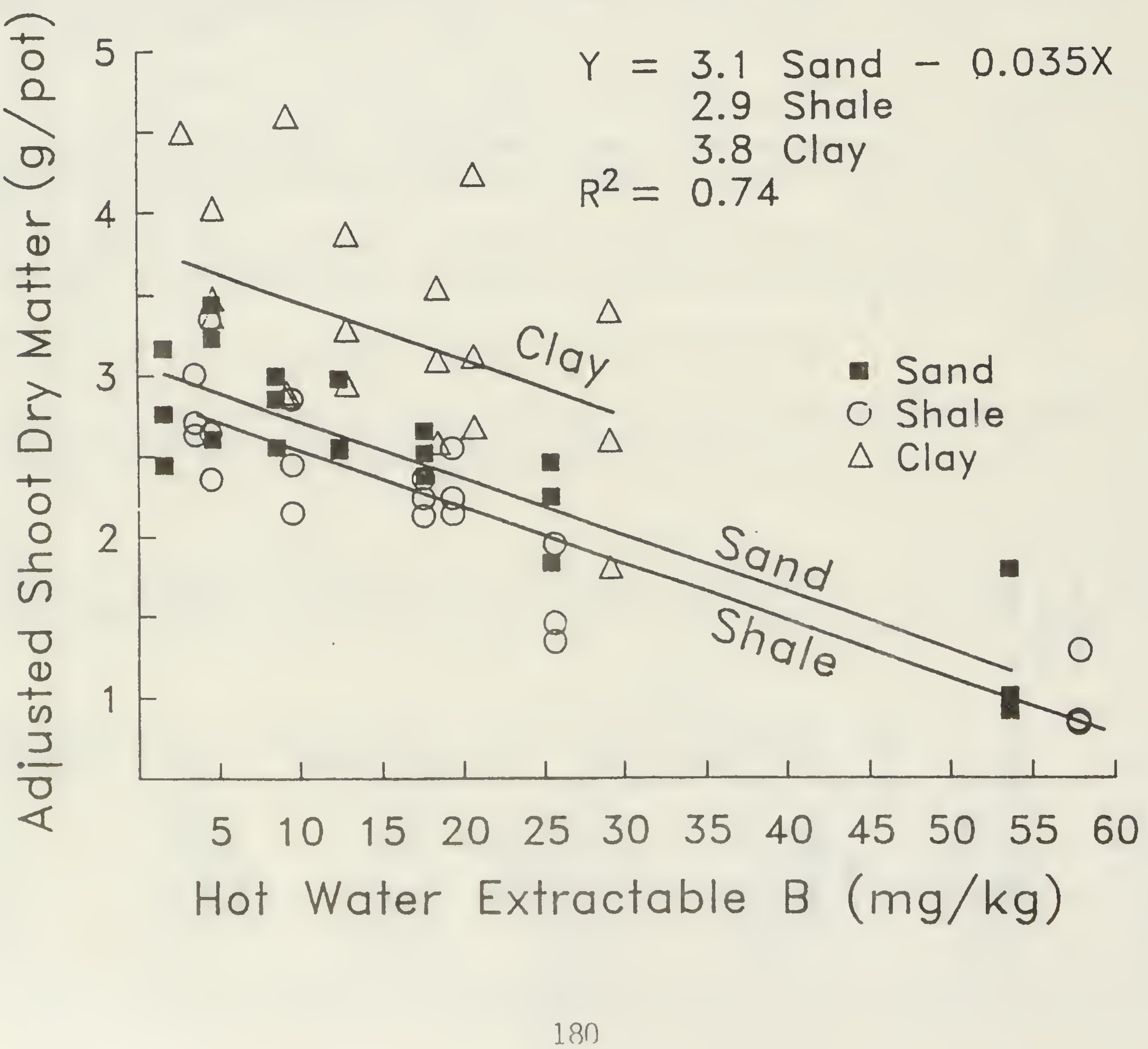
Table 3. Thickspike wheatgrass survival, length of leaf tip necrosis, height, dry matter production, and plant B concentration as affected by soil and hot water extractable B.

SOIL	HWE-B	SURVIVAL AFTER 38 DAYS	LEAF TIP NECROSIS DAY 52	65	80	100	HEIGHT DAY 24	38	52	65	80	100	DRY MATTER PRODUCTION SHOOT	ADJUSTED SHOOT	ROOT
	mg kg^{-1}	no. pot^{-1}	cm				cm						g pot^{-1}		
SAND															
CONTROL	1.3	11.7	0.4	0.8	0.7	0.3	12.0	18.7	21.3	27.7	28.7	31.3	2.95	2.81	6.81
	4.6	11.7	1.8	3.3	2.3	0.9	12.3	19.3	21.7	29.7	32.0	31.7	3.24	3.09	5.49
	8.6	13.0	2.3	3.8	2.7	1.1	11.0	18.7	22.7	29.7	31.0	31.3	2.96	2.81	3.90
	12.2	10.3	3.2	4.2	3.4	1.4	10.3	16.3	23.0	30.7	29.3	34.3	2.74	2.69	2.07
	17.7	8.7	3.2	3.7	3.5	2.7	9.3	16.7	23.3	32.3	32.0	35.3	2.34	2.50	1.98
	25.3	9.7	3.1	3.7	3.7	2.2	9.0	13.0	20.7	29.0	29.3	33.7	2.09	2.16	0.63
	53.7	6.0	4.2	3.0	2.7	2.9	7.0	9.0	15.0	23.7	25.3	31.0	0.82	1.21	0.51
	SE	0.7	0.3	0.3	0.2	0.2	0.5	0.8	0.7	0.7	0.6	0.7	0.19	0.14	0.92
CLAY															
CONTROL	2.8	10.7	0.3	0.7	0.9	0.5	11.3	18.7	24.3	30.3	34.0	35.7	5.45	4.40	4.04
	4.7	10.3	0.6	1.2	1.3	0.9	11.7	17.7	21.3	25.3	28.3	31.3	3.58	3.61	3.10
	9.1	9.7	1.1	1.8	2.0	1.6	11.7	17.7	23.7	27.3	29.0	33.0	3.40	3.44	5.80
	13.0	9.0	1.6	2.3	2.5	2.0	11.7	19.3	22.7	26.7	27.3	31.7	3.37	3.31	5.71
	18.5	8.7	2.1	3.1	3.3	1.9	10.7	18.0	24.3	31.0	34.3	39.3	3.10	3.05	5.12
	20.8	10.7	3.6	4.1	4.2	3.3	10.0	17.0	23.0	30.7	34.3	35.0	3.37	3.31	3.52
	29.1	9.3	4.3	3.7	4.0	3.7	9.0	15.0	20.0	29.0	33.0	35.3	2.59	2.58	2.11
	SE	0.5	0.3	0.3	0.2	0.2	0.5	0.6	0.5	0.6	0.5	0.9	0.17	0.16	0.61
SHALE															
CONTROL	3.5	10.0	0.6	1.1	0.8	0.2	11.7	17.3	18.0	24.3	25.7	27.7	2.93	2.78	4.10
	4.3	12.7	1.2	1.7	1.1	0.4	11.0	17.0	18.0	25.7	25.3	30.0	2.75	2.78	4.77
	9.6	9.3	1.5	1.8	1.9	1.2	11.3	18.7	19.7	27.0	27.0	31.7	2.54	2.48	1.55
	17.7	10.3	2.3	2.5	2.7	1.3	13.0	18.0	20.3	27.7	28.0	31.0	2.32	2.22	2.18
	19.2	8.3	2.5	2.8	2.9	2.2	10.0	16.3	18.3	28.7	27.7	30.7	2.27	2.31	1.55
	25.2	8.3	3.0	3.5	3.3	2.6	9.0	15.7	16.3	24.0	25.7	30.7	1.56	1.59	1.20
	57.9	5.7	3.5	2.0	2.8	2.6	6.7	9.7	12.0	19.0	23.7	25.0	0.82	0.98	0.35
	SE	0.7	0.2	0.5	0.3	0.3	0.6	0.6	0.6	0.8	1.0	0.9	0.23	0.15	0.53

relationship with HWE-B for the 24, 38, and 52 day data across all soils. Plant height measurements taken at day 65, 80, and 100 did not show any consistent relationship to HWE-B level of the soil material. Although, plants grown in the sand 53.7 and shale 57.9 mg/kg B treatments were visibly stunted.

Regression analysis showed that shoot dry matter production per pot (Table 3) was a function of HWE-B, soil material, and the number of pots per plant. Covariate analysis was used to adjust shoot dry matter production means for plant number per pot (Table 3). Percent reduction in shoot production as affected by B level was calculated using the fitted regression equation for adjusted means (Figure 1). Control treatment shoot production yields obtained from the regression equation were used as the maximums. Hot water extractable-B levels resulting in a 10% reduction in shoot growth were 9.9, 11.3, and 13.5 mg/kg HWE-B for the sand, shale, and clay, respectively. A 20% reduction occurred at 18.7, 18.9, and 24.0 mg/kg HWE-B for the sand, shale, and clay. When averaged across soils, the 10% reduction occurred at 11.6 mg/kg and the 20% reduction occurred at 20.5 mg/kg.

Figure 1. Adjusted thickspike wheatgrass shoot dry matter from three soils as related to hot water extractable B levels.



We hypothesize that thickspike wheatgrass grown in sand was more B sensitive than when grown in clay because of drier growth conditions attendant in the sand material. Plants grown in the sand regularly needed supplemental water, indicating that the water holding capacity of this soil was insufficient to sustain plant growth through the two week watering cycle. Supplemental watering was not required for the other two soil materials. Reductions in soil water content could exacerbate B toxicity to plants by increasing the in situ soil solution B concentration (Roundy, 1985). This higher soil solution B concentration would not be reflected in HWE-B values. Certainly some adsorption and/or precipitation would occur but if the rate and extent of these processes were inadequate to maintain B concentrations, a more concentrated B solution would result. It is also likely that drought stress reduces plant tolerance to B. Greater B sensitivity in the sand was also observed in the leaf tip necrosis data.

Since plants grown in the shale were not water stressed, we hypothesize, that the wheatgrass grown in the shale material did not perform as well as the clay because of the higher salinity of the shale (Table 1). Bingham et al. (1987) found no interaction between salinity and B concentration relative to dry shoot weights of wheat (Triticum aestivum L.) when salt levels approached 4.8 dS/m. However, increasing salinity did significantly reduce shoot production. Similar mechanisms appear to be operative in this study. The primary evidence to suggest that factors other than B toxicity may be affecting growth was that B toxicity symptoms were about equal and in some cases actually less severe in the shale compared to the clay grown plants.

During the root washing process it was noted that roots in the higher HWE-B levels were usually thinner than those in the lower levels. Schuman (1969b) had similar observations of tall wheatgrass roots. A greater amount of tillering was also observed in the lower B treatments. Further, it was observed that there were many more fine roots in the clay than in the sand and shale soil materials. Regression analysis of the root production data showed a natural logrithmatic relationship between root production per pot and HWE-B (Figure 2). There were no differences detected in root production among soil materials. Percent reduction in root production per pot was calculated using the regression equation. Results indicated a 10% reduction in root production at 3.8 mg/kg and a 20% reduction at 6.6 mg/kg B.

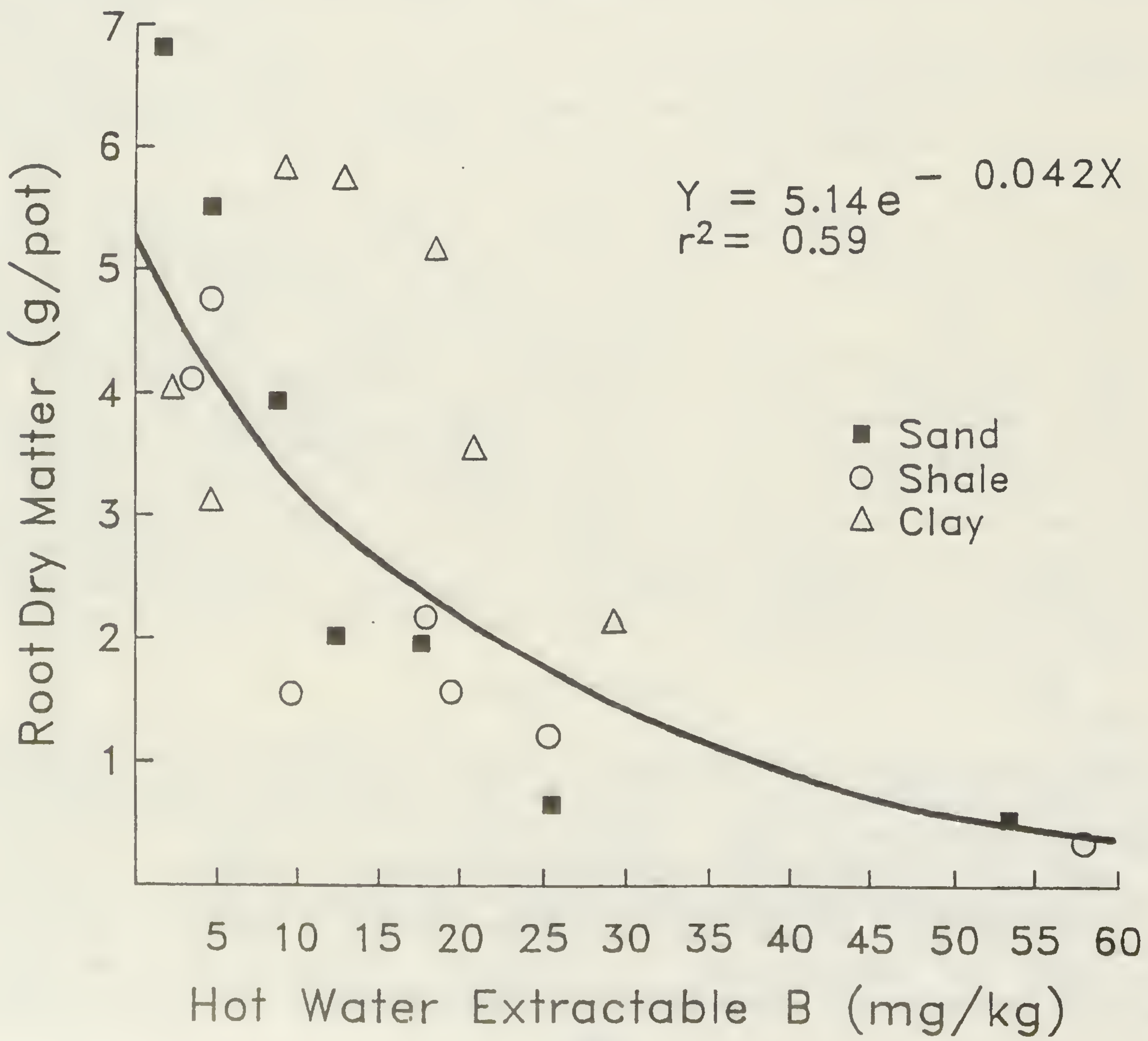
CONCLUSIONS

Shoot and root biomass reductions corresponding to a 5 mg/kg HWE-B level suggest that native plant species, respresented by thickspike wheatgrass, may indeed exhibit B tolerance beyond that level set as unsuitable for agricultural crops. Prior to considering a B suitability level greater than 5 mg/kg HWE-B for reclamation of mined land soils, other factors identified in this study must be considered. Droughty conditions appear to exacerbate B toxicity responses as demonstrated by plant response

to the sand compared to the clay treatments. Root growth was also found to be three times as sensitive to B as shoot growth. As observed in the shale material, other factors, such as salinity, can affect plant growth even though there may not be an interaction with B toxicity. These factors in combination with B toxicity could haave a cumulative impact on plant growth.

The ramifications of this study are that the B suitability level at the specific coal mine where soil samples were taken was increased above 5 mg/kg HWE-B for overburden material placed within the 1.2 m plant rooting zone. The revised standard was increased in two phases to a level of 11.5 mg/kg HWE-B. A field monitoring program involving vegetation cover and productivity sampling, plant analysis to detect elevated plant B levels, and spoil/soil sampling to document any upward migration of B is required for regraded spoil with B levels between 8.0 and 11.5 mg/kg HWE-B. No monitoring is required where regraded spoil has B levels less than 8.0 mg/kg HWE-B. The 5.0 mg/kg HWE-B standard remains in effect for replaced topsoil due to the greater sensitivity of the roots to B.

Figure 2. Thickspike wheatgrass root dry matter as related to hot water extractable B levels.



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SEED SOURCE DIFFERENCES IN GERMINATION UNDER SNOWPACK IN NORTHERN UTAH

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ABSTRACT

Different seed accessions of widely distributed native species differ markedly in their germination response to conditions under winter snowpack. These response differences may affect spring emergence and establishment following autumn seeding. In seed burial experiments at a mountain brush site in northern Utah, germination rates under snowpack correlated well with rates observed in continuous laboratory chill. Seed accessions of big sagebrush (*Artemisia tridentata*), rubber rabbitbrush (*Chrysothamnus nauseosus*), antelope bitterbrush (*Purshia tridentata*), firecracker penstemon (*Penstemon eatonii*), and Palmer penstemon (*Penstemon palmeri*) from warm winter collection sites germinated more quickly under snowpack in the field than accessions from cold winter collection sites. These findings suggest that seed accessions collected from sites that do not match planting site climate could misinterpret environmental cues and germinate at an inappropriate time, resulting in seeding failure. Careful matching of wild-collected seedlots of native species to site conditions could increase the probability of successful stand establishment.

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INTRODUCTION

When species included in a seed mixture for artificial revegetation fail to establish a satisfactory stand, many reasons may be given as cause for the failure. Weather events may have been unfavorable or competition from weeds or more aggressive seeded species may have prevented seedling survival. Perhaps the seeds were planted too deep or planted into an inadequately prepared seedbed. Seeds may have lost viability or at least vigor in the time between testing and planting. It is difficult to know after the fact which factors may have been most important. Some factors, such as the weather, are not under human control. The best we can do is optimize variables under our control to increase the chances of successful stand establishment.

If seedlots of native species collected from wildland stands are utilized, another set of variables becomes important. Not only is it necessary to use species adapted to the planting site, but the particular ecotype used may determine success or failure. It is well known that many western shrub species show strong ecotypic differentiation as adults in characteristics such as drought and frost tolerance. More recent discoveries indicate that seeds themselves may show ecotypic differences.

Seed germination response under a particular set of conditions is related to the fate of seeds germinating under those conditions in the context of parent population habitat. For example, the consequences of germinating quickly at near-freezing temperature would be different for warm desert and high mountain populations. In a warm desert habitat, rapid germination under cold, moist winter conditions would increase seedling survival chances by permitting establishment prior to the onset of spring drought. In a high mountain environment, similar cold, moist conditions would be experienced under snowpack, but rapid germination under these conditions would decrease seedling survival chances because of frost and damping-off risks. We would therefore expect seeds from warm desert populations of a species to germinate more rapidly at near-freezing temperatures than seeds from high mountain populations.

Habitat-correlated variation in germination rate under moist chill conditions in the laboratory has been documented for several species including big sagebrush (Artemisia tridentata) and rubber rabbitbrush (Chrysothamnus nauseosus) (Meyer et al., in press; Meyer et al., 1989). Moreover, these differences in laboratory germination patterns for big sagebrush and rubber rabbitbrush have been related to differences in emergence and survival in contrasting habitat types (Meyer and Monsen, in press). First-year return on seed for big sagebrush and rubber rabbitbrush in small field plots was significantly higher when site-matched seedlots were used.

Conclusions from field plot experiments are limited by the fact that seeds not resulting in visibly emerged seedlings in spring cannot be accounted for accurately. It cannot be determined which seeds died before germinating, germinated but failed to emerge, were killed postemergence but prior to sampling, or remained ungerminated in the soil.

In this experiment, seed accessions from different habitats for five species were planted in retrievable nylon mesh packets. This made it possible to compare germination rates under winter snowpack in the field with rates in laboratory chill experiments for the same seedlots. We also compared germination rates under snowpack among species and among accessions within a species.

METHODS

We included five species in this study, with seed collections from three populations for each species (Table 1). Collections were made during the 1988 field season. The seed was cleaned and stored unsealed under laboratory conditions until the initiation of the burial experiment.

Field Burial Experiment

Twenty-four seed packets were prepared for each of the 15 collections. Approximately 200 seeds were weighed for each packet and placed in a fine nylon mesh square along with an identifying tag. Color-coded wrapped wire was used to secure the seeds in the packet

Table 1. Collection location and climate information for 15 seed collections used in the field burial and laboratory chill experiments. Within each species, locations are ranked from warmer to colder winter based on mean January temperature

Location	Latitude/Longitude	Elevation (m)	Mean January Temperature (C)
Rubber Rabbitbrush (_Chrysothamnus nauseosus_)			
Leeds UT	37°20'N 113°35'W	1140	2.8
Nephi Canyon UT	39°42'N 111°43'W	1780	-5.0
Hailstone UT	40°36'N 111°24'W	1840	-6.1
Big Sagebrush (_Artemisia tridentata_)			
Snow's Canyon UT	37°12'N 113°37'W	1020	1.7
Mayfield UT	39°09'N 111°43'W	1690	-2.5
Point of Rocks WY	41°39'N 108°44'W	2210	-7.8
Antelope Bitterbrush (_Purshia tridentata_)			
Boise Front ID	43°37'N 115°59'W	890	-3.6
Tremonton UT	41°50'N 112°12'W	1480	-5.0
Mtn. Dell UT	40°47'N 111°42'W	1780	-6.7
Firecracker Penstemon (_Penstemon eatonii_)			
Snow's Canyon UT	37°12'N 113°37'W	1020	1.7
Thistle UT	39°59'N 111°30'W	1660	-2.2
Provo Canyon UT	40°21'N 111°32'W	1720	-2.8
Palmer Penstemon (_Penstemon palmeri_)			
Snow's Canyon UT	37°12'N 113°37'W	1020	1.7
Kolob Road UT	36°16'N 113°06'W	1480	0.6
Pine Valley UT	37°25'N 113°32'W	2000	-2.2

by folding up the corners and twisting the wire around the top, party-favor style. For the antelope bitterbrush packets, 100 seeds were counted rather than weighed.

The field site for the burial experiment is near the mouth of Hobble Creek Canyon, 4 miles east of Springville, Utah, at an elevation of 1530 m. The study site is in the mountain brush vegetation type, dominated by Gambel oak (Quercus gambelii) and mountain big sagebrush (Artemisia tridentata ssp. vaseyana). Mean annual precipitation is approximately 460 mm, while mean January temperature is approximately -2.0°C.

The burial site was tilled and leveled by hand-raking early in the fall. On November 22, 1988, one seed packet of each accession was buried under each of 24 hardware cloth cones. The antelope bitterbrush seeds were buried at a depth of 1 to 2 cm, while the remaining packets were pressed into the soil surface, which was muddy at the time. A light straw mulch (<1 cm) was sprinkled over each group of 15 packets prior to placement of the rodent-proof cone. The cones were arrayed in two rows at intervals of approximately 0.5 m. Each burial spot was marked with a 1.5 m flagged bamboo stake to facilitate relocation during the winter.

The burial plot area was snowcovered within 24 hours after burial and remained under snowpack until March 4, 1989. The snowpack varied in depth from 10 to 50 cm. Seed packets were excavated at 1-month intervals as long as snowpack persisted, with an additional excavation just prior to the bare-off in early March. Another set of samples was excavated on March 13, just 9 days after the last snow melted. Two replicate sets of packets, one from each row, were removed on each excavation date.

Following retrieval, the packets were kept under cold, moist conditions until laboratory processing a few hours later. Each packet was opened and the number of germinated seeds recorded. Remaining seeds were placed on moistened blotters in petri dishes and incubated at 15°C with a 12-hour photoperiod for 28 days. Germinated seeds were counted and removed at least weekly. At the end of the incubation period, ungerminated seeds were evaluated using a cut test to determine the number of viable but dormant seeds remaining.

Laboratory Chill Experiments

Laboratory chill experiments were initiated soon after field burial took place. For each of the 15 accessions, four replications of 25 seeds each were used. Seeds of big sagebrush and rubber rabbitbrush were placed on top of moistened blotters in petri dishes and incubated in the light (12-hour photoperiod, cool-white fluorescent lights) at 1°C. Seeds of antelope bitterbrush, firecracker penstemon, and Palmer penstemon were incubated in the dark at 1°C but were exposed to light weekly when germinated seedlings were counted and removed. At the end of the cold-incubation period (24 weeks for the penstemons, 20 weeks for the other species), seeds were transferred to the 15°C chamber for a week, and any further germination was recorded. Ungerminated seeds were evaluated using a cut test to determine the number of viable but dormant seeds remaining.

Data from the field and laboratory experiments were converted to a percentage of viable seed basis for graphical representation. Final germinable plus dormant percentages from the laboratory chill experiment were used as the estimate of total viable seed.

RESULTS

All accessions of each species had at least some germination under the snow during the 100 days that snowpack was continuously present (Figure 1). Considerable variation in germination rate occurred under snowpack both among species and within species.

Antelope bitterbrush seeds from the warmest collection site (Boise Front) had initiated germination at 60 days and germinated to over 70% by bare-off (Figure 1). The cold winter Mountain Dell seedlot germinated little under snowpack, while the Tremonton seedlot showed an intermediate response. Germination under snowpack was generally slower than germination in the laboratory chill experiment. The differences among accessions were more pronounced in the field, but the rank order remained the same. When seeds were placed in incubation at 15°C following excavation on March 2, over 95% of all viable seed of all three accessions germinated within a week. When packets were excavated on March 13, essentially all viable seeds had germinated.

Big sagebrush seeds germinated much more slowly under snowpack than in the laboratory chill experiment, and differences among accessions were not as clear (Figure 1). The warm winter Snow's Canyon collection showed higher under-snowpack germination than the other two accessions on only one date. Low temperature germination rate for big sagebrush is greatly increased by light (Meyer et al., in press). This may account for much of the difference between field and laboratory results, especially for the Snow's Canyon collection, which has shown a strong light requirement in other experiments (Meyer, unpublished data). All three accessions germinated to over 50% during 100 days of snowpack, and all remaining viable seeds germinated within a week when incubated at 15°C in the light. When packets were excavated 9 days after snowmelt, all remaining viable seeds had germinated.

Germination patterns under snowpack for rubber rabbitbrush were similar to laboratory chill results (Figure 1). The warm winter Leeds collection had the fastest germination and the cold winter Hailstone collection had the slowest germination in both field and laboratory chill experiments. By the end of 100 days of snowpack, all viable seeds of the Leeds and Nephi Canyon accessions had germinated. No viable ungerminated seed of any accession was recovered when seeds were excavated 9 days after snowmelt.

Seeds of Palmer penstemon germinated much more slowly under snowpack than in laboratory chill (Figure 1). Palmer penstemon seeds are strongly light-requiring and probably germinate more slowly in dark chill. In the laboratory chill experiment, the seeds received light at least once a week during reading. At the end of the 100 days of snowpack, the warm winter Snow's Canyon collection had germinated to 30%, while the colder winter Pine Valley collection had only germinated to 9%. Most of the viable Palmer penstemon seeds remaining ungerminated at the end of 100 days of snowpack were dormant and did

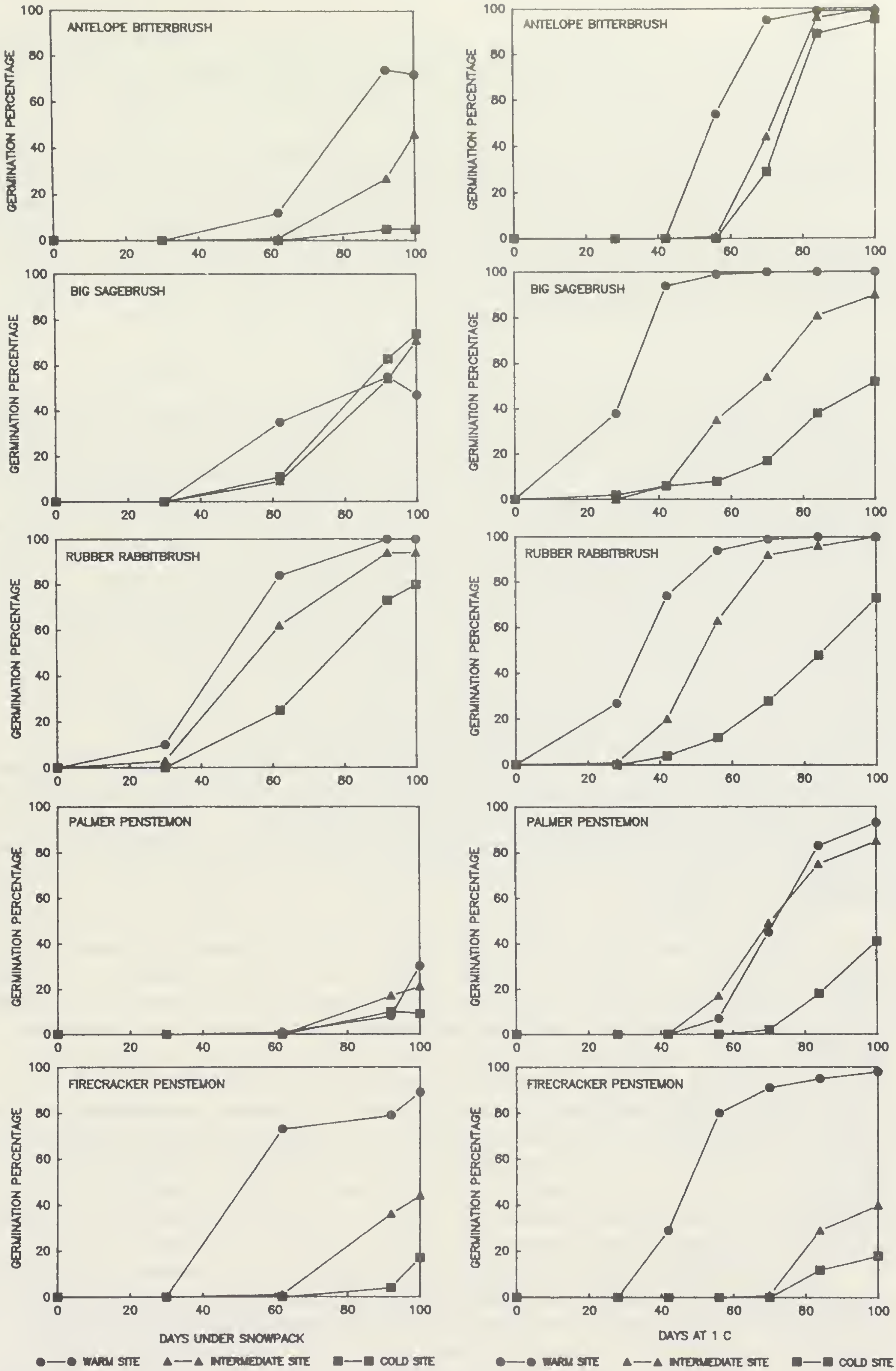

Figure 1. Germination time course plots for 15 seed accessions belonging to five species during 100 days under snowpack in the field (left side) and during 100 days of incubation at 1°C in the laboratory (right side). Results are presented on a percentage of initial total viable seed basis.

not germinate when incubated at 15°C in the light. These seeds were largely nondormant at the time of burial. Palmer penstemon seeds may be induced into secondary dormancy by chill (Allen and Meyer, in press).

Germination rates for firecracker penstemon seed accessions under snowpack were similar to germination rates in laboratory chill (Figure 1). The warm winter Snow's Canyon collection germinated much more quickly than the other two collections in both experiments. As with Palmer's penstemon, viable ungerminated seeds recovered at the end of the snowpack period were almost all dormant. These seeds were also dormant at the time of burial.

DISCUSSION

This field burial experiment demonstrated that seeds of a range of native species can germinate under snowpack during the winter. The details of the results are specific to conditions of temperature and snowfall at the burial site during the course of this particular experiment, but the implications are far-reaching. Conditions during the winter of burial were well within the range of conditions likely to be encountered at middle and upper middle elevation sites throughout the Intermountain West. The fact that seeds germinate under the snow means that they are irreversibly committed prior to exposure to spring conditions and that they are in a more vulnerable state with regard to freezing, dessication, and attack from fungal pathogens. They no longer have the option of delaying germination until conditions are potentially more favorable.

The concordance of field burial germination rates with laboratory chill germination rates varied among species. For rubber rabbitbrush and firecracker penstemon, results were similar in the two experiments. For the remaining species, rank order of accessions was the same in the two experiments, but rates were lower in the field setting.

In the laboratory, seeds are incubated on blotters that permit good aeration, are held constantly at an above-freezing temperature, and are exposed to light at least during the weekly reading. In the field, temperatures may drop below freezing when the snow is too thin to insulate against low ambient temperatures. Seeds are suspended in saturated soil, restricting oxygen diffusion, and light conditions under mulch and snowpack are different from laboratory light conditions. Different species and accessions seem to be more or less sensitive to variation in these factors. But the fact that the seed collection rank order of germination was the same in field and laboratory for all five species indicates that the laboratory chill procedure can at least provide an index of relative response for accessions within a species.

For all five species in both field burial and laboratory chilling experiments, warm winter accessions germinated faster than cold winter accessions. The field results confirm the results of this and earlier laboratory chilling experiments and indicate that among-accession variation in germination response under laboratory conditions can be interpreted in terms of predicted response in the field.

For the shrubby species in this experiment, essentially all viable seeds that had not germinated under snowpack germinated within

9 days in the field once snowmelt had occurred. None of the accessions had any mechanism for conserving ungerminated viable seeds, at least under the particular conditions of this field burial. The penstemon species presented a marked contrast. Most of the nondormant seeds of both penstemon species germinated under snowpack. A large dormant seed reserve remained at the end of the post-melt-off germination period. These perennial forb species, which are much shorter lived than the shrub species, apparently have well-developed mechanisms for ensuring viable seed carryover from year to year. The ability to resist germination during or immediately after chill is part of this persistent seedbank strategy.

The message for practitioners of revegetation from this study is quite clear. It does matter where the seed of wild-collected native species is harvested. For species of wide ecological amplitude, it matters even more. Seed accessions harvested from sites that do not match planting site climate could misread environmental cues and germinate at an inappropriate time, resulting in failure to establish a stand. It would be worthwhile for buyers of wild-collected seed to press for a more reliable system of source identification or to contract seed collection from wildland stands of suitable ecotypes. Any additional cost should be more than compensated by the increased probability of obtaining a stand.

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Planning, Rehabilitation, and Treatment of Disturbed Lands
Billings Symposium, 1990

SEEDING EQUIPMENT EFFECTS ON ESTABLISHMENT OF BIG SAGEBRUSH ON MINE DISTURBANCES

S. B. Monsen and S. E. Meyer[1]

ABSTRACT

Five planting methods were tested with and without jute mulch to determine the effect on big sagebrush (Artemisia tridentata) seedling emergence and survival on the Beacon Pit mine near Battle Mountain, Nevada. Seeding using surface-compacting seeders or broadcasting on a firm seedbed resulted in significantly higher emergence and year-old stand density than drilling or harrowing in broadcast seed. Of seedlings that emerged, approximately 35% survived the first summer and 21% survived the following winter. Use of jute mulch increased initial emergence, but there was no significant difference in stand density between mulch and no-mulch treatments by the end of summer. Survival of emerged seedlings was highest in broadcast treatments and lowest in row seeding treatments. Broadcasting resulted in better spatial dispersion of seeds. The results suggest that much of the first-year mortality was due to self-thinning of closely spaced seedlings. Year-to-year differences in weather conditions strongly influence seedling establishment, especially in semiarid environments. But seedbed conditions can be altered through the use of specific planting techniques to increase probability of big sagebrush emergence and survival.

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INTRODUCTION

Big sagebrush (Artemisia tridentata) is a dominant species in semiarid shrubland ecosystems throughout the Intermountain West (Blaisdell et al. 1982). Shrub reestablishment on mine disturbances in these ecosystems has proven surprisingly difficult, especially for small-seeded species such as big sagebrush (Howard et al. 1979; Luke and Monsen 1984). Several problems may be involved.

Shrubs are rarely seeded alone. Most often they are combined in seed mixtures that include a high proportion of perennial grass species. They may have trouble establishing under these conditions because of competition from other seeded species, especially grasses (Richardson et al. 1986). Competition from weeds such as Russian thistle (Salsola spp.) and cheatgrass (Bromus tectorum) may also lower seedling survival (Winward 1985; Young and Evans 1989).

Some shrub species are more readily established on topsoiled areas than directly onto mine spoils or wasterock material (Monsen and Richardson 1984). This may be because of improved soil physical or chemical properties or because of the presence of inoculum of rhizosphere symbionts such as mycorrhizae in topsoil (Cundell 1977).

Shrub establishment failure is sometimes attributable to characteristics of the seedlot used. The seed may be of poor quality, or may have been collected from an ecotype poorly adapted to the site (Meyer and Monsen, in press).

In the present study, we attempted to minimize such shrub establishment problems, so that we could concentrate on another major source of stand failure in the seeding of small-seeded shrub species, namely seedbed preparation and seeding methodology. We seeded a high quality seedlot of a locally collected big sagebrush ecotype onto a topsoiled mine disturbance, without competition from other seeded species or weeds. We wanted to find out how much difference seeding technique would make in initial emergence and in first-year survival for big sagebrush.

Another major factor in shrub seeding success, as in all seeding endeavors in semiarid climates, is the weather. The field experiment described here was set up at four semiarid mine sites but significant emergence and establishment took place at only one location. Failure to establish a stand regardless of seeding treatment at the other three sites was readily accounted for by unusually dry winter conditions. The take-home message is clear: even the best seeding methods cannot compensate for a truly dry year. The best we can hope for is to increase the probability of successful stand establishment in years that are marginal or better by using the best seed and the best seeding techniques available.

METHODS

The seeding experiment was established in November 1987 at the Beacon Pit Mine, an inactive barite mine located 15 miles southeast of Battle Mountain, Nevada, at an elevation of 4,600 feet. Mean annual precipitation is approximately 8 inches. The site is dominated by native Wyoming big sagebrush (A. tridentata ssp. wyomingensis), with whitestem rubber rabbitbrush (Chrysothamnus nauseosus ssp. hololeucus) as the early successional dominant on the coarse-textured mine waste

dumps. The rabbitbrush eventually gives way to big sagebrush through natural recruitment processes (Meyer and Monsen, unpublished data).

The experimental design was a split plot with mulch treatment (with or without jute mulch) as the main plot and seeding treatment as the subplot. The experiment was replicated six times. Each seeding treatment unit was 5 feet x 40 feet; half of each seeded strip was covered with jute mulch following seeding.

The 105 foot x 80 foot plot prepared for the seeding experiment is located inside an exclosure bounded by a livestockproof and rabbitproof fence. This exclosure was installed as a part of earlier studies (Richardson 1979). The mine spoils material was covered to a depth of 8 to 12 inches with topsoil collected from a big sagebrush area immediately southwest of the exclosure. The area was then disked three times and harrowed twice to create a level, uniform seedbed. The soil was moist at the time but worked up well, and a satisfactory seedbed was created.

Seed for the study was collected on the day of planting (November 19, 1987) in the immediate vicinity of the mine. It was hand-stripped from the plants and screened to remove twigs and coarse debris that might bridge up in the seeding equipment. A subsample of the bulk seedlot was used to determine the bulk weight needed to deliver an average of 75 seeds per square foot. Seed viability (as determined in a germination test carried out in February 1988) was 97%.

The seeding methods used were broadcast seeding with a hand-pulled fertilizer spreader, broadcast seeding as above followed by harrowing, seeding with a cultipack (Brillion) seeder, seeding with an Oyer (compact row) seeder, and drilling with John Deere flexplanters set to seed at a depth of 0.25 to 0.50 inches. Seeding equipment was pre-calibrated to seed the designated volume of bulk seed over the 5 foot x 40 foot strip. The bulk seed was mixed with rice hulls as necessary to give a volume of seed material that could be dispensed with reasonable accuracy through each seeder.

Initial emergence in the spring was evaluated approximately a week after snowmelt, on March 22, 1988. At that time, five 1-foot quadrats were randomly located in each of the 60 experimental units (five seeding treatments x two mulch treatments x six replications) and their corners marked with flagged pins. The sampling frame was divided into 36 compartments to facilitate seedling counts. These 300 quadrats were reinventoried three times, May 9-10, 1988, August 11, 1988, and March 11-12, 1989.

Results of the seeding study were analyzed using analysis of variance procedures appropriate for a split plot design with repeated subsampling. The Student-Newman-Keuls means separation test was used for evaluation of differences among treatment means.

RESULTS

Initial seedling emergence after snowmelt in mid-March was high, averaging 32 seedlings per square foot, a seed return of approximately 43%. Differences among seeding treatments were highly significant ($p<0.0001$). The Oyer compact row seeder--a device that compacts the soil, then presses the seed in rows into the surface--had the highest initial emergence, 60 seedlings per square foot (Figure 1). Broadcast seeding and seeding with the Brillion (cultipack) seeder gave

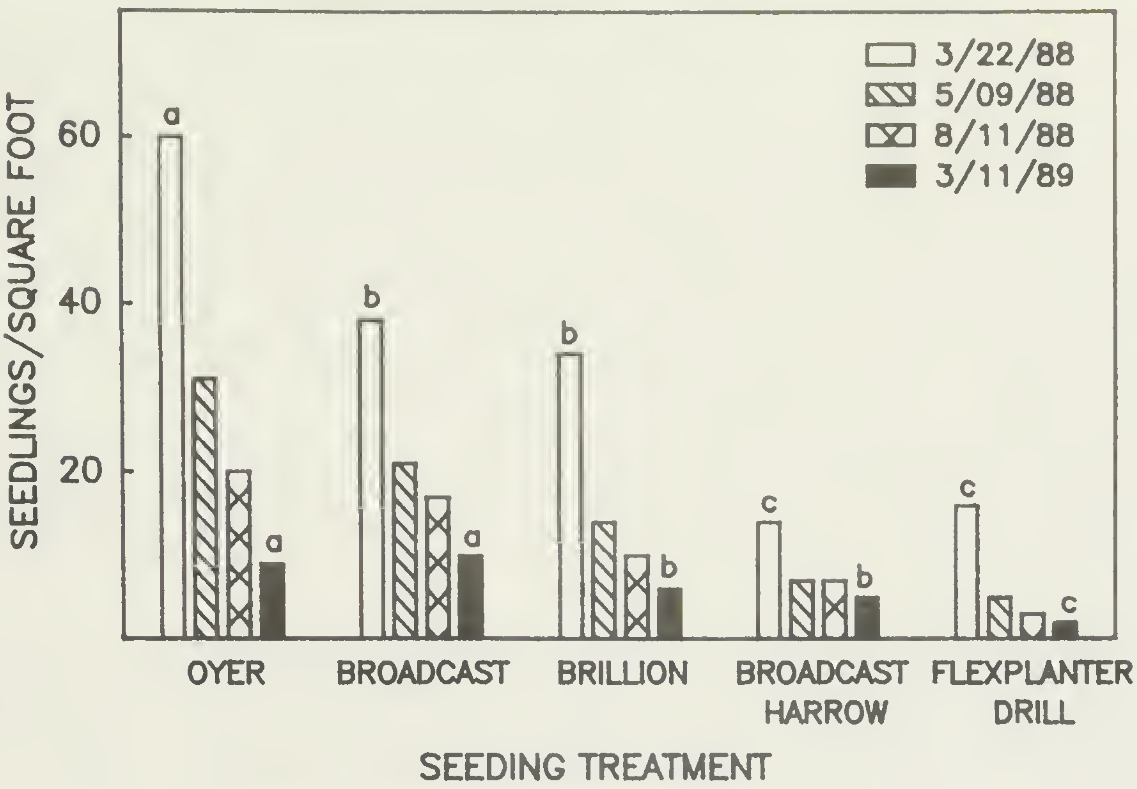

Figure 1. Mean number of seedlings per square foot on four census dates for each of the five seeding treatments. For the first and last census dates, treatment columns headed by the same letter are not significantly different at the $p<0.05$ level.

comparable intermediate results (38 and 32 seedlings per square foot, respectively). The flexplanter drill treatment and the broadcast-and-harrow treatment yielded comparable but lower initial seedling densities (15 and 16 seedlings per square foot, respectively).

When plots were reinventoried in mid-May, seedling numbers had decreased by approximately half (Figure 1). This mortality was quite evenly distributed among treatments, so that relative differences remained largely unchanged.

By mid-August, further mortality had reduced seedling numbers to approximately 35% of the number initially observed (Figure 1). Relative survival, i.e., percentage of emerged seedlings surviving, was highest (44 and 45%) in the broadcast and broadcast-and-harrow treatments and lowest (21%) in the flexplanter drill treatment. The rank order of treatments in terms of surviving seedlings per square foot remained unchanged.

When plots were reinventoried in mid-March 1988, a year after initial emergence, mean seedling numbers were 21% of the number initially observed (Figure 1). The Oyer and broadcast treatments had similar high mean seedling densities (9 and 10 seedlings per square foot, respectively). The flexplanter drill treatment had the lowest density (2 seedlings per square foot), while the Brillion (cultipack) and broadcast-and-harrow treatments had similar intermediate densities (6 and 5 seedlings per square foot, respectively).

The two broadcast treatments continued with relatively high survival percentages in the spring 1988 inventory, 27% for broadcast and 32% for broadcast-and-harrow. The Brillion (cultipack) treatment had an intermediate relative survival percentage (19%), while the two

row seeding treatments (Oyer and flexplanter drill) had similar relatively low survival, near 15% in both cases.

Jute mulch had a significant and positive effect on initial seedling emergence ($p<0.0037$) (Figure 2). Mean number of seedlings per square foot was 39 under jute mulch and 26 in the no-jute control. By mid-May, the seedling density difference between the two treatments was no longer statistically significant. It continued to diminish through the summer and following winter, so that the two treatments had similar seedlings densities (7 versus 6 seedlings per square foot for mulch and no-mulch respectively) in the spring 1988 census. Relative survival was higher in the no-mulch treatment (24 versus 18%) and compensated for the higher initial emergence under mulch.

The mulch treatment by seeding treatment interaction term in the analysis of variance was not significant for any inventory date, indicating that the two effects operated essentially independently of each other. Mulching was not able to compensate for less effective seeding techniques.

Results of the spring 1988 inventory expressed in terms of return on seed sown indicate a rather high mean seed return of 9%. Even the worst seeding treatment, the flexplanter drill, gave a creditable seed return of 3%, while the best treatments gave returns of 12 and 13%.

DISCUSSION

The return on seed sown in this study was exceptionally high in comparison with field seedings with big sagebrush, where returns of 1% are considered acceptable (Monsen and Richardson, 1984). Several factors probably contributed to this high return, including lack of competition from other seeded species or weeds, high quality seed of a

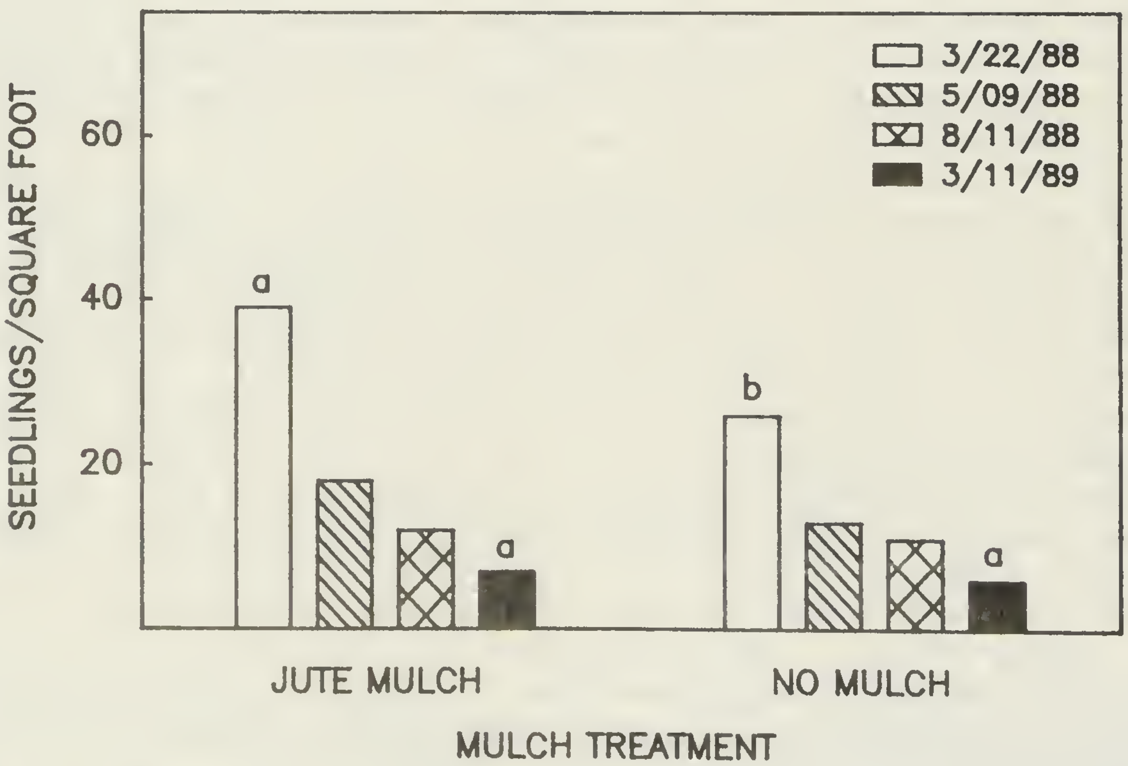

Figure 2. Mean number of seedlings per square foot in jute mulch versus no mulch treatments on four census dates. For the first and last census dates, columns headed by the same letter are not significantly different at the $p<0.05$ level.

locally-adapted ecotype, and reasonably good conditions for seedling establishment and survival for the duration of the study. While detailed weather records are not available for the mine site itself, weather records for nearby Battle Mountain indicate that precipitation the winter of 1987-1988 was above normal, with good early spring moisture. When the site was visited on March 8, 1988, about half the plots were still under snowpack. A week later, the snow was off, but the soil was still saturated across all the plots. At the time of sampling, the surface was just beginning to dry out. Early spring snow followed by gradual warming appears to present ideal conditions for big sagebrush emergence.

Seeding treatment had a strong effect on emergence and survival of big sagebrush seedlings. Those treatments resulting in direct burial of the seed or in the creation of a loose, sloughing seedbed had significantly lower emergence. Treatments that planted the seed into the surface of a firm seedbed resulted in significantly higher emergence. Big sagebrush seeds are small (0.022 grams/100 seeds or approximately 2 million seeds per pound of pure seed). They emerge best from surface sowing because they lack reserves for emergence from depth. Other field studies have also shown that big sagebrush establishes best when surface sown onto a firm seedbed (Booth and Schuman 1981; Haferkamp et al. 1987; Monsen and Richardson 1984).

Survival of emerged seedlings was highest in broadcast treatments, which dispersed the seed randomly over the surface, and lowest in treatments that concentrated the seeds in rows. The seeding rate of 75 seeds per square foot was substantially higher than seeding rates used in field seedings (Luke and Monsen 1984; Richardson et al. 1986). It probably resulted in heightened intraspecific competition, especially in the row seeding treatments. Much of the mortality was probably a consequence of self-thinning of closely spaced seedlings.

Jute mulch had a positive effect on seedling emergence, but lower relative survival under the mulch cancelled out any beneficial effect from increased emergence. We obtained a similar effect from jute mulch in another small plot study at a Wyoming big sagebrush study site in central Utah (Meyer and Monsen, in press). Whether this effect is peculiar to jute mulch is not known, but it is at least clear that jute mulch produced no net benefit.

Based on this study, we would recommend broadcast seeding as a method for planting big sagebrush provided that a good seedbed is first prepared. The loose, sloughing seedbed left by ploughing, disking, or drilling of large-seeded species would not be an optimum surface for seeding small-seeded species such as sagebrush. Use of a Brillion seeder would be an improvement over broadcasting in this situation. Drilling big sagebrush seed caused a definite decrease in both emergence and survival and is not recommended.

In spite of the fact that treatment differences were highly significant in this study, a satisfactory stand in terms of return on seed was produced even in the least favorable treatment. This suggests that seeding method may not be the most important variable in big sagebrush establishment as long as a reasonably firm seedbed is available. Using high quality seed of an adapted ecotype and controlling competition from weeds and other seeded species may be as important as the seeding technique used. The latter may be achieved through interseeding techniques or scalping, so that the shrub seed is

planted into small areas that are largely free of seeds of weeds or other seeded species (McKell 1986; Rosenstock et al. 1989; Stevens 1985).

Success or failure of a big sagebrush seeding is ultimately in the hands of the weather. In a good year reasonable stands will probably result even with relatively low seeding rates as long as the above precautions are heeded. In a marginal or poor year, it will be difficult to obtain a stand no matter how high the seeding rate, unless some form of microhabitat manipulation such as snow harvesting is used. For this reason, relatively low seeding rates of 0.25 to 0.50 pounds of pure live seed per acre are recommended. This would result in seed densities of approximately 10 to 20 per square foot. Even with a seed return as low as 1%, plant densities of 1 to 2 per 10 square feet, or approximately 4,000 to 8,000 plants per acre, would be obtained.

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Billings Symposium, 1990

Rooting-Depth of *Atriplex canescens* (fourwing saltbush) in mine spoils at the Navajo Mine, Northwestern New Mexico

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ABSTRACT

The distribution of roots was determined for fourteen mature plants of *Atriplex canescens* (fourwing saltbush) growing on mine spoils at the Navajo Mine in northwestern New Mexico and for two plants growing in contiguous unmined native soil. In all instances the amount of roots, by length, was negatively correlated with depth and positively correlated with percent water-content of the soils. The majority of roots (59%) were in the upper 100 cm; 72% were in the upper 150 cm; and 84% were in the upper 200 cm. These percentages were higher for plants growing on backslopes (64%, 77% and 88%, respectively) and much higher for those growing in native soils (84%, 93% and 96%, respectively). Most of the roots (83%) were less than 0.1 mm in diameter, and 93% were less than 0.5 mm in diameter. Plants growing in topsoiled sites had more roots per unit volume of soil (1.3 cm per cc of soil) than those growing in non-topsoiled sites (1.1 cm per cc of soil.). Those growing in backslopes had more roots (1.3 cm per cc of soil) than those growing in swales (1.0 cm per cc of soil) and those growing in soils that contained no fly-ash had more (0.78 cm per cc) than those growing in soils that contain fly ash (0.12 cm per cc of soil). Plants growing in native soils had a greater proportion of their roots near the surface than plants growing in mined soils. Plants growing in swales had a greater proportion of their roots below two meters than plants growing on backslopes.

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INTRODUCTION

Atriplex canescens (Pursh) Nutt. (fourwing saltbush) is one of the most commonly used shrub species for reclamation of coal-mine spoils in the western United States. It has proven to be far superior for such use because of its capacity to grow in soils that are high in pH and dissolved salts, and because it is nutritious and palatable to livestock and wildlife (Welch and Monsen, 1983). Also, its wide distribution throughout western North America provides ecotypes that are adapted to many of the climates in western North America.

Very little has been reported on the rooting depth of fourwing. Wallace et al. 1980 reported root-depth of A. canescens to be mostly less than 50 cm in desert soils of southern Nevada. In southern New Mexico one fourwing plant growing beside a well was reported to have roots more than 20 ft deep (Foster et al. 1928). No reports were found of the rooting depth of fourwing in reclamation sites.

An opportunity to examine rooting-depths of fourwing growing on mine spoils was recently provided at the Utah International Navajo mine in northwestern New Mexico in response to a need to determine appropriate depths for burying fly-ash containing selenium. Because *Atriplex canescens* has been reported to be a secondary selenium accumulator (Rosenfield and Beath, 1964), it is important to bury selenium-bearing fly ash sufficiently deep to ensure that fourwing growing in overlaying spoils do not have access to and accumulate selenium to toxic levels.

METHODS

Excavations

A variety of sites were selected for root-depth studies at the Navajo Mine in order to identify effects of soil type, landscape, topsoil, buried fly-ash and slope on root growth and distribution. A total of 16 rooting profiles were examined in pits dug with a backhoe within populations of mature fourwing saltbush (Table 1). Fourteen of the pits were on reclaimed mine-land and two were on native soils undisturbed by mining. The two major landscapes of the mined - land sites were: (a) backslope (the rectilinear portion of the landscape between the crest and the base of the toeslope): 8 sites, and (b) swales (the base of the toeslope): 6 sites. Two of the swale locations ((pits 4,6) were concave, and the other four had positive drainage, two of which (pits 10, 12) had topsoil. Four pits were in spoils that had received approximately 15 cm (6") of topsoil. Two of these (pits 9, 11), were backslopes, and the other two (pits 10, 12) were swales. Four pits were in ash-burial sites, two were on backslopes (pits 1,2), and two in swales (pits 13, 14). Both of the pits excavated in native soils were in swales with positive drainage. One was in a sandy-textured Razito soil type (pit 15), and the other was in a fine loamy-textured Blancot soil type (pit 16).

The 8 backslopes that were sampled had an average slope of 8.9% with a range of 4 to 15%. The six pits located in swales had an average slope of 3.3% with a range from 0 to 7%. The depth of ash-burial ranged from 110 cm (pit 2) to 300 cm (pit 14). The depth of topsoil ranged from 10 cm (pit 10) to 25 cm (pit 9, 11, 12).

Table 1. Types of Sites Excavated

				Reclaimed Site Characteristics				
Pit I.D.#	Native	Reclaimed	Backslope	Swale	Topsoiled	Non-Topsoiled	Buried Ash	No Ash
1		X	X			X	X	
2		X	X			X	X	
3		X	X			X		X
4		X		X		X		X
5		X	X			X		X
6		X		X		X		X
7		X	X			X		X
8		X	X			X		X
9		X	X		X			X
10		X		X	X			X
11		X	X		X			X
12.		X		X	X			X
13		X		X		X	X	
14		X		X		X	X	
15	X							
16	X							

The topsoil was generally sandy material and contained gravel-size, coarse fragments, usually sandstone.

Five main reclamation areas were sampled at the mine. On each of these, reclamation was initiated between 1975 and 1978. The spoil materials were highly variable between pits and within pits. The materials were derived from sandstone, shale, and siltstone geological materials, each with various degrees of rock hardness. The variation in amount of large fragments (>25 cm in diameter) was considerable from pit to pit. Generally, the majority of coarse fragments were cobble size, 7.5 cm - 25 cm (3" - 10") or gravel size 0.2 cm - 7.5 cm (0.8" - 3"). Pits 5 and 10 had several boulders larger than 100 cm (3 feet) which presented some serious problems in both digging and sampling.

SAMPLING

Roots of *A. canescens* were exposed alongside mature plants. In each pit, samples of roots were removed from a vertical transect directly below the crown of a plant. Each transect was approximately 10 cm wide and extended from the surface to the bottom of the pit. Pit depth varied from 250 cm to 400 cm but was usually about 350 cm (Table 2). Root samples were collected by removing a 1000 cc sample of soil containing the roots from consecutive 25 cm increments along the sampling transect. An additional 500 cc sample was taken at each 25 cm increment for determination of soil-water content. Sampling began on December 19, 1986 and was completed on January 9, 1987.

MEASUREMENTS

Each of the samples collected was poured into a bucket of water containing calcium chloride to facilitate separation of the roots from the soil. Using sieves, all roots in each sample were extracted and placed in petri dishes containing water (Fig. 1), and then were separated into diameter-size classes for length measurements. The diameter-size classes recognized were <0.1mm, 0.1 to 0.5mm, 0.5 to 2.0mm and >2.0mm. Actual root lengths were measured on all roots over 0.5 mm in diameter; the lengths of smaller roots were obtained by estimation, using, as indices, small samples which were measured in detail.

Roots in each sample were segregated into three diameter classes for determination of root weights: (a) less than 1 mm, (b) 1 to 5 mm, (c) more than 5 mm. They were oven dried for 24 hours at 50°C and weighed to the nearest 0.01 gram. Root volumes for samples in each pit were estimated by multiplying root length by πr^2 where r is the average radius of the size class. Root surface-areas were computed by multiplying root length by average root circumference (πd), where d is the average size-class diameter. Soil-water content was determined gravimetrically by drying the soil samples at 105°C and expressing amounts on a mass basis (Table 6).

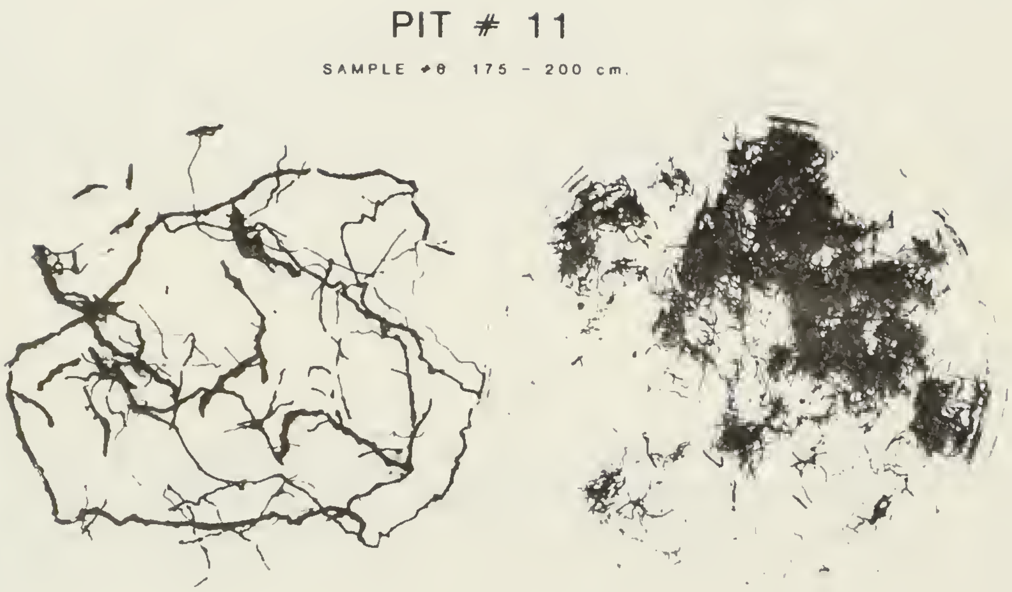

Figure 1. Photograph of roots taken from sample #8 (175-200 cm), Pit #11. The petri-dishes contain all of the roots present in a 1000 cc. sample of soil taken from a 25 cm. increment along a vertical transect in this pit, below the crown of an ***Atriplex canescens*** plant. The roots in each of the other pits were similarly arranged for measurement.

DATA ANALYSIS:

Root measurements in the 16 pits were grouped as follows to make several comparisons:

a) Reclaimed (14 pits) vs. native (2 pits),
b) Swale (6 pits) vs. backslope (8 pits),
c) Ash (4 pits) vs. non-ash (10 pits)
d) Topsoil (4 pits) vs. non-topsoil (10 pits).

RESULTS

In all pits most of the roots were near the soil surface (Fig. 2, 3, 4, 5, Table 2, 3, 4, 5). Those on reclaimed sites had 59% of the roots in the upper 100 cm, 72% in the upper 150 cm, 84% in the upper 200 cm, and 90% in the upper 250 cm (Figure 2, Table 5). These proportions were higher for plants growing in native soils: 84% in the upper 100 cm, 93% in the upper 150 cm and 96% in the upper 200 cm. (Figure 2, Table 5). Plants growing in swales had a larger proportion of deeper roots than those growing on backslopes: 15% of the roots of plants growing in swales were below 250 cm compared to only 6% for those growing on backslopes. (Figure 3, Table 5).

There were no significant differences in the distribution of roots growing in topsoiled areas compared to those having no topsoil nor in those containing buried fly ash compared to those containing no fly ash (Figure 4, 5, Table 5). However, there were significantly more roots produced by plants growing in topsoiled areas than by those growing in non topsoiled areas and by those growing in areas that contained no fly ash than by those in areas containing buried fly-ash. (Table 4). Plants growing in swales produced more roots per volume of soil than those growing on backslopes. (Table 4).

Roots in the smallest diameter group (<0.1 mm) were, by far, the most abundant, by length, constituting 83% of all roots in pits on reclaimed sites (Table 3). The next largest diameter group (0.1 - 0.5 mm) constituted 10.7% of all roots, 4.6% were in the 0.5 - 2.0 mm group and only 2.0% of the roots had diameters larger than 2.0 mm (Table 3).

In several pits the excavation exposed portions of well developed taproots with strong lateral branches. In a few instances portions of these taproots occurred within some of the samples from the vertical transect (e.g. Pits 1, 4, 6, 7, 10). Although massive by weight and volume, these large roots contribute very little to root length.

The amount of roots in each size class and percent water in the soil samples were negatively correlated with soil depth (Table 8). Each root diameter size class was positively correlated with water content (Table 8). The water content of soils in pits excavated in swales was significantly higher than in those excavated in backslopes, higher in pits excavated in mine spoils than in those excavated in native soils and higher in those excavated in areas treated with topsoil than in those excavated in sites that had not been topsoiled. No differences were seen in the moisture content of soils

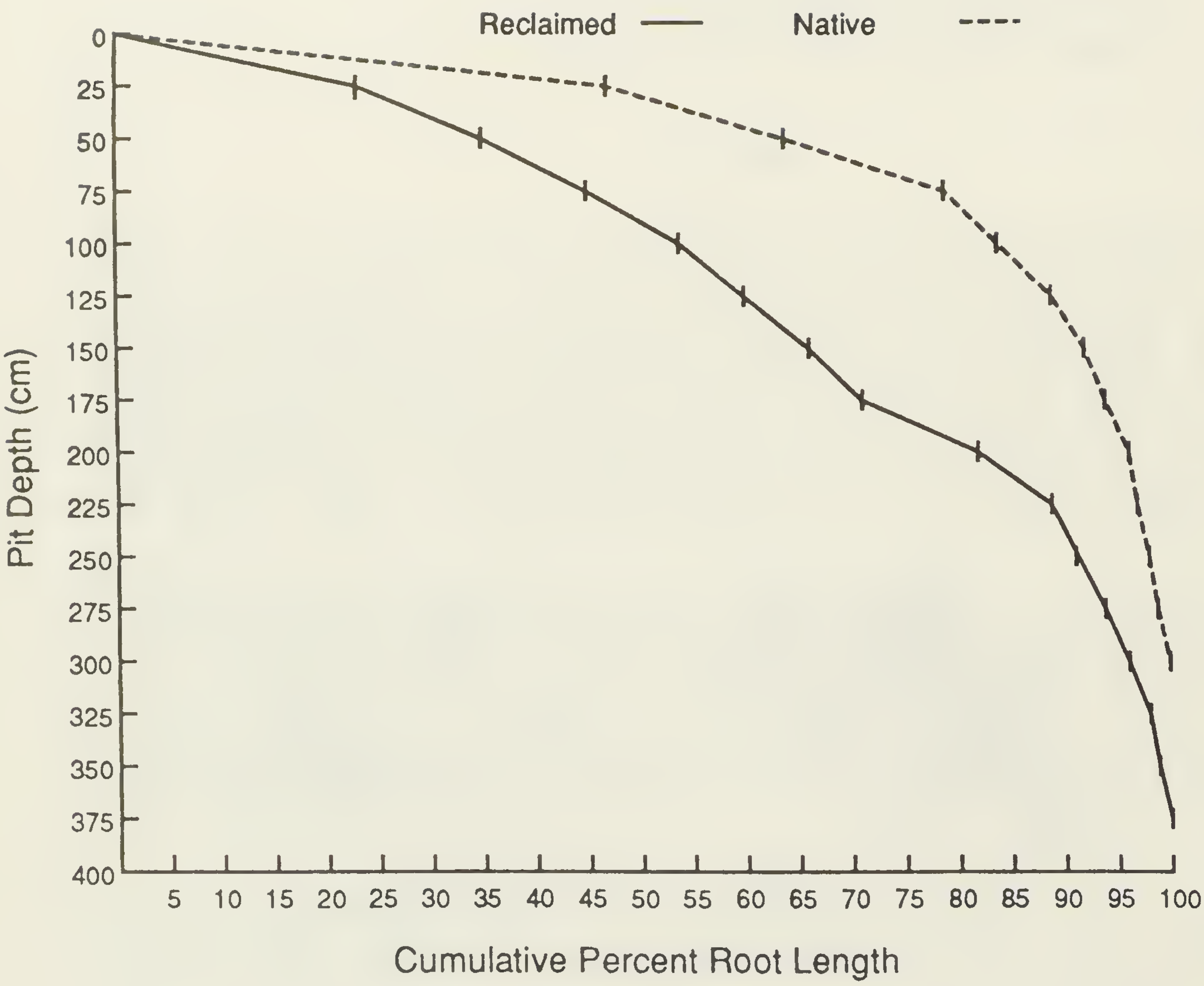

Fig. 2 Comparison of cumulative percent root-length with depth, in pits dug in reclaimed sites and pits dug in native, unmined sites.

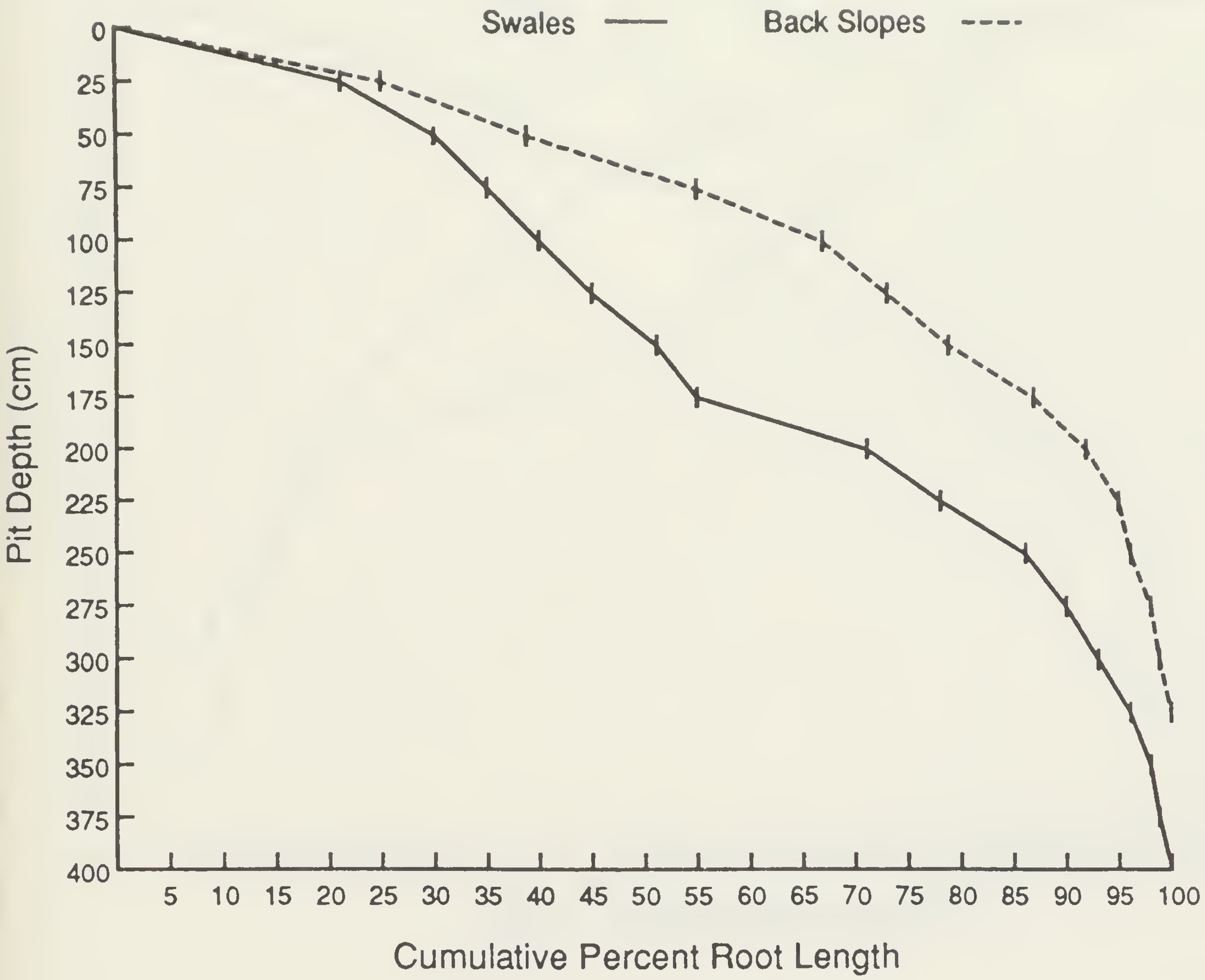

Fig. 3 Comparison of cumulative percent root-length with depth, in pits dug in swales and pits dug in back-slopes.

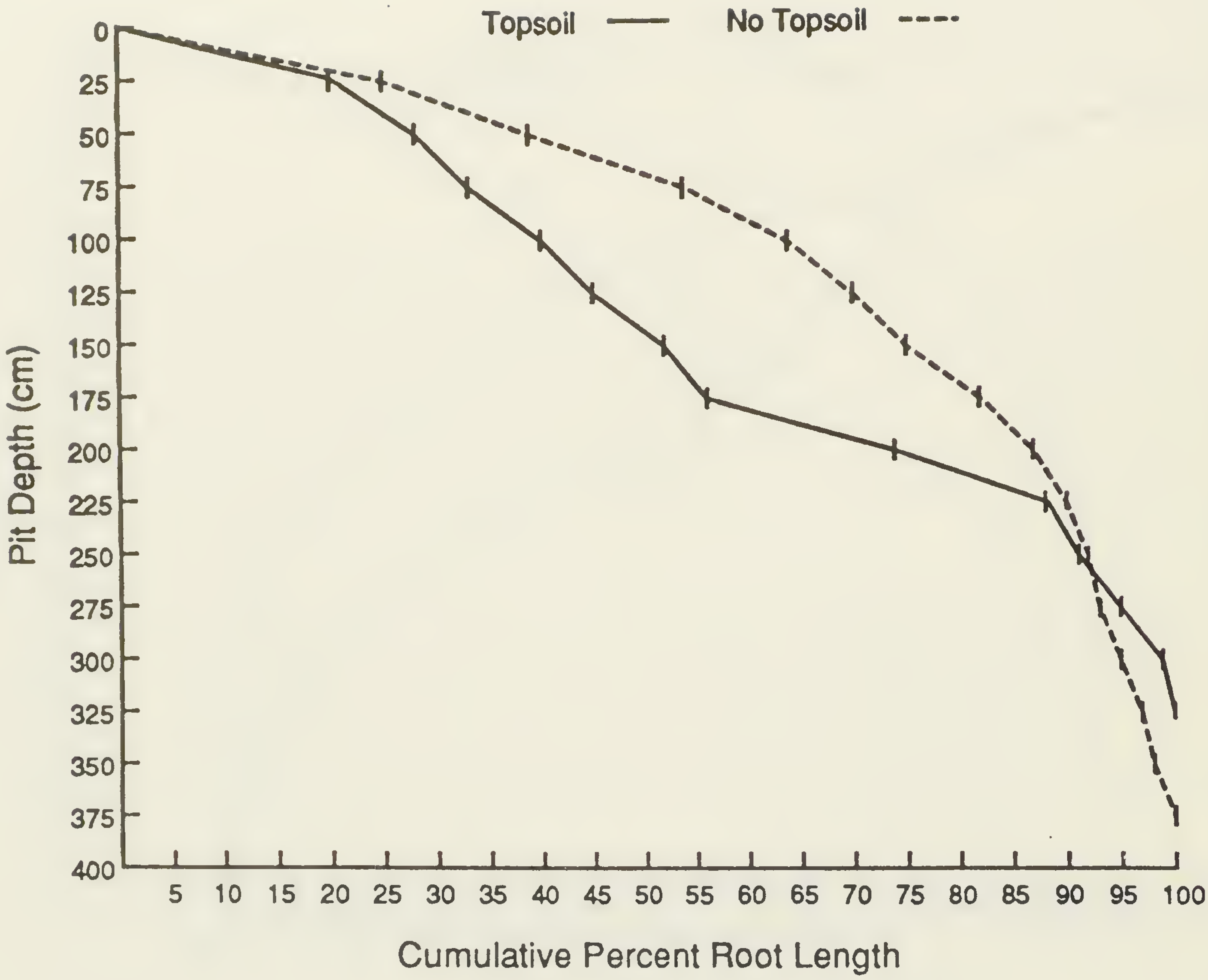

Fig. 4 Comparison of cumulative percent root-length with depth, in pits dug in sites treated with topsoil and in sites receiving no topsoil.

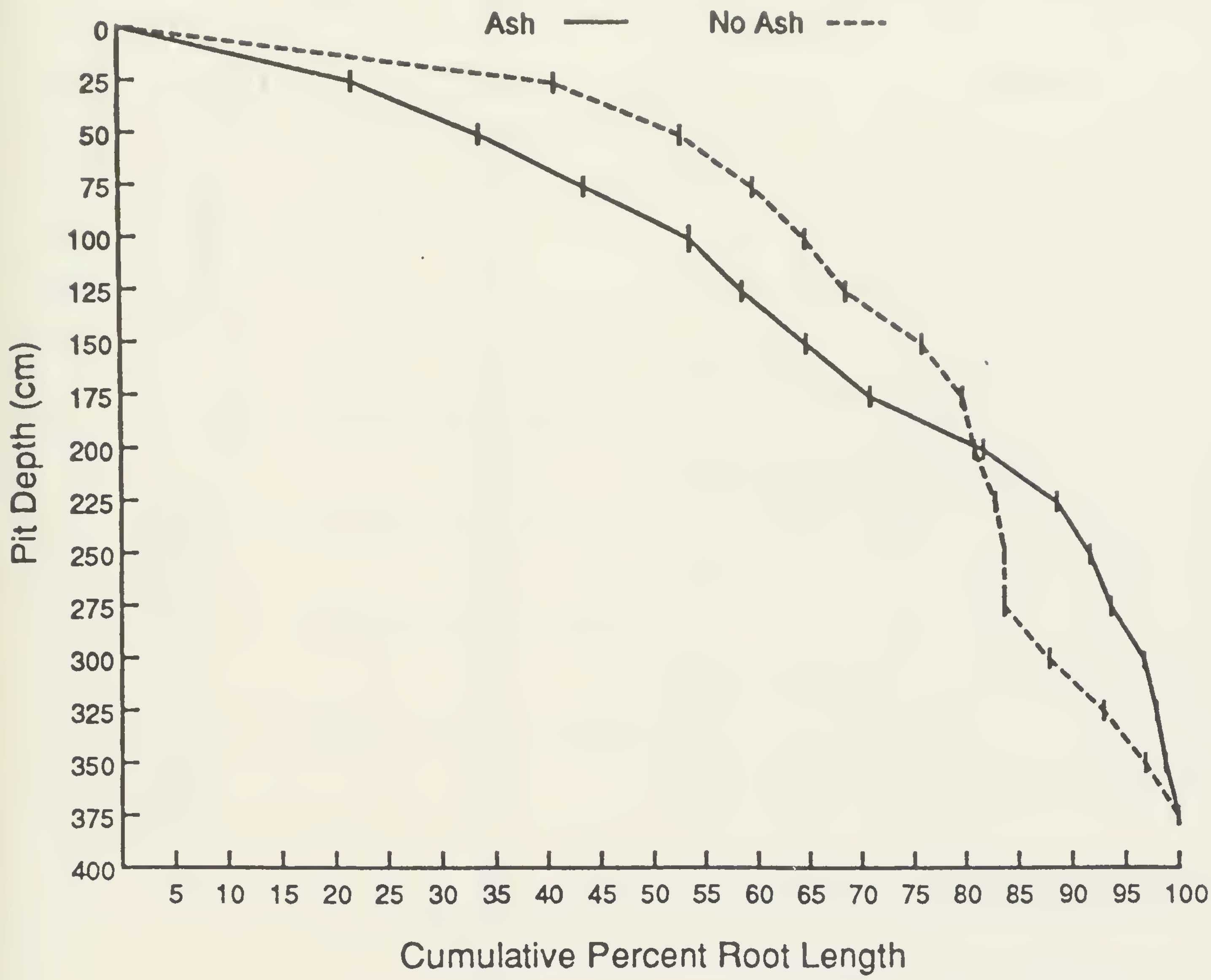

Fig. 5 Comparison of cumulative percent root-length with depth, in pits dug in sites that contained buried fly-ash and in pits containing no fly-ash.

Table 2. Total root length (cm) with depth in each pit.

Depth (cm)	PIT NUMBER 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
25	550	107	1619	4357	6398	1466	1444	1086	1587	4307	3494	370	611	1963	3305	2585
50	245	199	2121	2329	4826	471	425	320	1178	2668	188	40	203	309	1036	1178
75	151	153	316	915	8702	637	359	190	739	1291	135	222	40	196	1211	633
100	147	93	223	384	5770	365	750	194	943	1121	363	1206	61	77	388	314
125	91	104	127	376	2390	684	713	106	395	1764	474	235	47	28	333	301
150	73	190	84	517	1694	439	529	103	492	2212	682	472	105	188	92	300
175	1	155	103	792	2927	209	1039	223	370	809	345	253	76	99	51	169
200	1	105	114	1110	2203	238	357	75	75	8259	836	389	15	4	205	15
225	17	68	248	799	846	161	173	150	109	6562	278	105	1	3	174	4
250	33	43	286	463	224	184	161	38	57	1454	129	185	1	3	127	1
275			98	386	25	194	120	150	6	1260	549	150	2	5	22	101
300				750		146	79	128	15	1442	559	88	1	334	20	7
325				631		66	106	308	67	225	120	72	24	360	33	12
350				455		234	15	227	46	0	70	75	30	329	14	10
375				679		86							23	186		
400				406		22										
TOTAL	1309	1214	5338	15348	36006	5602	6268	3296	7078	33473	8222	3861	1238	4084	7007	5628

Table 3. Average root length (cm), percentages, and cumulative percentages of each root-diameter size-class at each depth on reclaimed sites.

Pit Depths (cm)	N	Root-diameter size-classes (mm) 0 to 0.1			0.1 to 0.5			0.5 to 2.0			Greater than 2.0 mm			All Roots		
		x	%	Cum %	x	%	Cum %	x	%	Cum %	x	%	Cum %	x	%	Cum %
0 to 25	14	1697	21.7	21.7	326	32.2	32.2	125	28.7	28.7	20	10.8	10.8	2168	22.9	22.9
25 to 50	14	883	11.3	33.0	142	14.0	46.2	50	11.5	40.2	33	17.9	28.7	1109	11.7	34.6
50 to 75	14	857	11.0	44.0	94	9.3	55.5	37	8.5	48.7	15	8.1	36.8	1003	10.6	45.2
75 to 100	14	678	8.7	52.7	108	10.7	66.2	23	5.3	54.0	26	14.1	50.9	835	8.8	54.0
100 to 125	14	458	5.9	58.6	37	3.7	69.9	25	5.7	59.7	18	9.8	60.7	538	5.7	59.7
125 to 150	14	453	5.8	64.4	53	5.2	75.1	32	7.4	67.1	17	8.7	69.4	556	5.9	65.6
150 to 175	14	425	5.4	69.8	60	5.9	81.0	31	7.1	74.2	13	7.0	76.4	529	5.6	71.2
175 to 200	14	904	11.6	81.4	50	4.9	85.9	30	7.0	81.2	8	4.3	80.7	991	10.5	81.7
200 to 225	14	589	7.5	88.9	53	5.2	91.1	32	7.4	88.6	6	3.3	84.0	680	7.2	88.9
225 to 250	14	187	2.4	91.3	24	2.4	93.5	16	3.7	92.3	6	3.3	87.3	233	2.5	91.4
250 to 275	12	206	2.3	93.6	23	1.9	95.4	6	1.2	93.5	13	6.0	93.3	248	2.3	93.7
275 to 300	10	301	2.7	96.3	30	2.1	97.5	19	3.1	96.6	5	1.9	95.2	354	2.7	96.4
300 to 325	10	173	1.6	97.9	16	1.1	98.6	3	0.5	97.1	5	1.9	97.1	198	1.5	97.9
325 to 350	9	135	1.1	99.0	7	0.4	99.0	20	3.0	100.0	3	1.0	98.1	164	1.1	99.0
350 to 375	4	224	0.8	99.8	12	0.3	99.3	0	0.0	100.0	6	0.9	99.0	243	0.7	99.7
375 to 400	2	181	0.3	100.0	20	0.3	100.0	0	0.0	100.0	14	1.0	100.0	214	0.3	100.0
Total	187	586			76			33			14			708	100.0	
%			82.7				10.7			4.6			2.0			100

Table 4. Average amount (cm) of roots at each depth in contrasting pit sites.

	Pit Site							
	Origin		Slope		Topsoil		Ash	
Depth (cm)	Native	Reclaimed	Swales	Backslopes	Yes	No	Yes	No
25	2945	2168	2179	2161	2690	1960	808	2713
50	1106	1109	1003	1188	1018	1145	239	1457
75	922	1003	550	1343	597	1166	135	1351*
100	351	835	536	1060	908	866	94	1132**
125	316	538	522	550	717	406	67	726**
150	196	556	656	481	965	392	139	722**
175	110	529	373	645	444	562	83	707**
200	110	991	1686	471	2415	422	31	1376**
225	89	680	1272	236	1764	247	22	943**
250	63	233	381	121	456	144	20	318
275	61	210	333	119	491	98	2	294
300	14	253	460	98*	526	144	84	321
325	22	141	230	75	121	150	96	160
350	12	106	187	45	48	129	90	112
375	0	70	162	0**	0	97	52	76
400	0	31	71	0	0	43	0	43
ALL	395	591	663	537**	822	498*	123	778****
N	32	224	128	96	64	160	64	160

*, **, ***, **** Significant at the 0.05, 0.01, .0001, and 0.0001 levels, respectively (Kruskal-Wallis Test)

Table 5. Cumulative percent of root length with depth in contrasting pit sites.

	Pit Site							
	Origin*		Slope**		Topsoil		Ash	
Depth (cm)	Reclaimed (N=14)	Native (N=2)	Swales (N=6)	Backslope (N=8)	Yes (N=4)	No (N=10)	Yes (N=4)	No (N=10)
25	29	46	29	29	25	31	37	26
50	42	64	38	45	32	46	52	38
75	50*	79	44	54	38	55	60	46
100	59*	84	53	64	51	63	66	56
125	65*	89	58	70	57	68	71	62
150	72*	93	65	77	65	74	80	69
175	78	95	69	84	70	81	85	75
200	84	96	77	88	81	85	88	82
225	88	97	82	92	88	88	89	87
250	90	98	85	94	91	90	91	90
275	92	99	87	96	95	91	91	93
300	95	99	91	97	98	93	93	95
325	97	100	94	99	99	96	96	97
350	100	100	97	100	100	98	98	99
375	100	100	99	100	100	100	100	100
400	100	100	100	100	100	100	100	100

* · ** Significant at the 0.05 and 0.001 levels, respectively (Kruskal-Wallis Test)

Table 6. Percent water content of soils at each depth in each pit.

	PITS																
Depth (cm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	$\bar{X}$
0-25	25.5	21.8	20.3	20.1	25.9	32.0	12.6	21.0	14.8	12.1	19.2	9.7	20.6	26.6	8.0	9.6	18.7
50	15.8	21.8	17.3	20.1	15.3	15.8	9.6	24.09	16.0	11.5	11.1	21.3	14.5	24.3	3.7	9.4	15.7
75	12.6	23.4	15.2	19.0	17.4	24.1	16.0	18.6	9.8	8.9	10.9	10.8	13.6	21.0	2.5	6.8	14.4
100	9.0	21.7	7.7	16.5	15.4	20.3	16.2	18.1	4.9	7.5	13.2	11.5	11.3	19.6	3.0	4.3	12.5
125	12.9	12.0	8.6	20.5	8.3	18.8	17.9	19.9	5.3	10.1	13.5	12.1	13.1	25.5	3.7	4.0	12.9
150	9.9	7.7	8.9	21.4	8.9	15.4	16.2	9.9	10.7	14.8	14.0	11.6	13.4	19.0	3.5	2.8	11.8
175	3.5	8.5	9.4	21.3	12.1	14.9	11.1	12.8	6.7	6.8	13.5	11.3	11.6	12.4	3.8	3.2	10.2
200	3.5	7.9	9.7	19.6	10.6	20.6	11.1	12.6	10.0	5.2	13.4	10.4	11.4	11.2	4.3	3.0	10.2
225	3.5	10.7	9.8	15.0	13.1	19.8	15.5	12.6	10.1	10.1	12.7	9.9	12.2	10.6	4.0	2.5	11.5
250	15.2	10.7	7.7	16.3	14.0	18.4	16.3	14.3	11.8	14.9	12.1	10.4	11.4	11.1	3.8	3.3	12.0
275			7.7	16.0	13.2	21.3	16.8	15.2	11.1	12.1	10.9	10.1	8.7	11.3	3.5	2.4	11.5
300				15.4	12.5	25.7	16.5	14.5	12.1	12.7	14.2	10.1	13.8	12.0	5.2	7.2	13.2
325				10.7		22.6	13.7	14.7	11.4	13.3	14.2	10.5	13.3	10.0	3.3	4.0	11.8
350				11.3		24.0		12.6	12.5	6.7		10.5	9.7	9.5	8.1	10.7	11.6

Table 7. Comparison of moisture content (percent gravimetric water) of soils in contrasting sites.

	Pit Site							
	Origin***		Slope*		Topsoil***		Ash	
	Native	Reclaimed	Swale	Backslope	Yes	No	Yes	No
% Water	4.86	14.17	15.42	13.21	11.33	15.33	14.4	14.1

* · *** Significant at the .05 and .0001 levels, respectively

Table 8. Correlation of amount of roots in each diameter size-class with depth and with percent gravimetric water in the top 350 cm (top 10 samples) in all pits (N=160)

		Diameter Class				
	Water	<0.1mm	0.1 to 0.5mm	0.5 to 2.0mm	>2.0mm	All Roots
Depth	-0.3862[a]***	-0.3481***	-0.4939***	-0.3654***	-0.2527***	-0.3822***
Water		0.1697*	0.2694***	0.2654***	0.1941***	0.1941**

[a] = Pearson correlation coefficient
* · ** · *** significant at the 0.05, 0.01, 0.001 levels respectively

in pits dug in areas containing buried fly-ash than in those dug in areas without fly-ash (Table 7).

After examination of various methods used to express the magnitude of root growth, root length was determined to be the best. As shown in Table 9, 10, measures of root surface-area, root weight, and root volume greatly overemphasize contributions of large diameter roots, which are relatively ineffective in mineral and water absorption. Since in this study, 98% of the roots, by length, were less than 2 mm in diameter (Table 3) the contribution of larger diameter roots to root length, and hence absorption, is minimal.

DISCUSSION

Most of the differences in amounts and distribution of roots in pits on contrasting sites appear to be directly related to differences in amount of available water. All root-diameter classes were positively correlated with water content of the soils (Table 8) and both water content and amount of roots were negatively correlated with depth. The production of a greater proportion of roots at deeper depths by plants growing in reclaimed soils, compared to those growing in native soils (Table 7) is probably due to deeper percolation of water in reclaimed areas. This may be the result of several factors including the following:

1. The looser, more skeletal (coarse fragments) mine-soils may have permitted deeper penetration of natural precipitation. This has probably been further amplified by the larger fragment sizes of newly reclaimed spoils.
2. "Piping" due to less compaction and the presence of larger fragments.
3. Irrigation of reclaimed sites would have added considerably more water than natural precipitation.
4. The long history of plant succession on the native sites may have resulted in an ecosystem containing several shallow rooted plant species that absorb the water before it can percolate very far into the soil.
5. Fossil water may still be present in these shales and sandstones that were buried anciently in the bottoms of seas. Such fossil water may contribute to total available water early in revegetation establishment, permitting root growth until it becomes depleted or unavailable.

The larger proportion of roots at lower depths in pits located in swales, compared to those located on backslopes (Table 5) is probably due to a higher water content at lower depths in swales provided by runoff from neighboring slopes in the area.

The distorted distribution patterns of roots in pits 5 and 10 (Table 2, Figure 2) are probably also the result of differential water distribution. The presence of large boulders in these pits apparently serve as localized water-sheds, resulting in elevated amounts of water and an accordingly increased amount of roots between and below the boulders.

Table 9. Comparison of percent of roots in each diameter size-class when measured by length, by surface area, and by volume.

	Percent when measured by:		
Diameter (mm)	Length (cm)	Surface Area $(cm)^2$	Volume $(cm)^3$
< 0.1	83.4	23.0	0.9
0.1-0.5	10.4	17.3	3.9
0.5-2.0	4.4	30.2	28.4
> 2.0	1.8	29.5	66.8

TAble 10. Percent of roots in each diameter size-class when measured by weight.

Diameter (mm)	Percent
< 1.0	4.6
1.0-5.0	15.5
> 5.0	79.9

The absence of differences in the distribution patterns of plants growing in mine spoils containing buried fly-ash compared to those containing no fly-ash as well as in those treated with topsoil compared to those receiving no topsoil (Tables 5, Figure 4, 5) is probably because of the absence of any factor which would cause a difference in water distribution between sites. Plants growing in areas containing fly-ash produced significantly fewer roots than those growing in sites without fly-ash (Table 4) but their distributions were similar. Consequently, fly-ash apparently has an inhibitory effect on root growth of fourwing independently of available water.

The larger amount of roots present in areas that had received topsoil (Table 4) corresponds with the significantly higher amount of moisture present in topsoiled areas (Table 7).

Since the upper 200 cm of soil contained 84% of all *A. canescens* roots in pits on reclaimed sites, more than 88% in pits having positive outslopes, and more than 96% in the two pits excavated in native stands (Table 5), mineral and water absorption below this depth on most reclamation sites at the Navajo Mine is probably minimal by this species. In time, as the soils become increasingly weathered and the amount of deep available water becomes further reduced, the absorbing root system may become even more shallow and approach that of existing native stands.

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REVEGETATION OBSERVATIONS AT SURFACE COAL MINES IN THE AXIAL BASIN, YAMPA RIVER BASIN, AND NORTH PARK, COLORADO

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ABSTRACT

Vegetative cover and woody plant density sampling was conducted on representative revegetated areas at surface coal mines in the Axial Basin, Yampa River Basin, and North Park, Colorado in 1984 and 1985. The same areas were sampled again in 1989. More recently reclaimed areas which, in some cases, were revegetated using different techniques were also sampled during 1989. The sampling indicated considerable variation in the apparent potential for achieving a diverse, permanent, and effective vegetative stand as required by state and federal statutes. Vegetative cover, woody plant density, and species diversity were evaluated with respect to seed mix, age of stand, and applicable success criteria.

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INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 requires coal mining companies to establish "a diverse, effective and permanent vegetative cover" on reclaimed lands. The Colorado Surface Coal Mine Reclamation Act of 1979 contains similar wording. Regulations pursuant to the Colorado Act (effective August 30, 1980) set out herbaceous cover and production, species diversity, and woody plant density as criteria for postmining vegetation to be judged adequate for final bond release. Coal operators in Colorado have operated under the existing revegetation requirements since the Federal Interim Regulations went into effect on December 13, 1977.

In order to monitor the status of revegetation with respect to apparent potential for meeting regulatory requirements, the authors initiated an ongoing sampling program in 1984 at selected mines in three mining areas of northwest Colorado, where the majority of the state's active surface coal mines are located. Data were collected in 1984 and 1985 in the Axial Basin, the Upper Yampa River Basin, and North Park in Colorado and observations were reported in Savage and Mathews (1985). The same areas sampled in 1984 and 1985 were resampled in 1989, along with selected additional areas. Our primary objective in this paper was to evaluate trends resulting from the longer term analysis with respect to the apparent potential for the selected reclaimed sites to meet applicable revegetation success criteria.

Axial Basin

The Axial Basin is a large west-northwesterly trending anticline in southern Moffat and northern Rio Blanco Counties in the northern portion of the Uinta Coal Region (Fig. 1). There is only one coal mine presently operating in the area, Colowyo Coal Company's Colowyo Mine (Colowyo). Colowyo is a 4 million ton/year open pit mine. Eight coal seams are extracted to a depth of approximately 122 m. (400 ft.) using a combination of truck/shovel and dragline techniques.

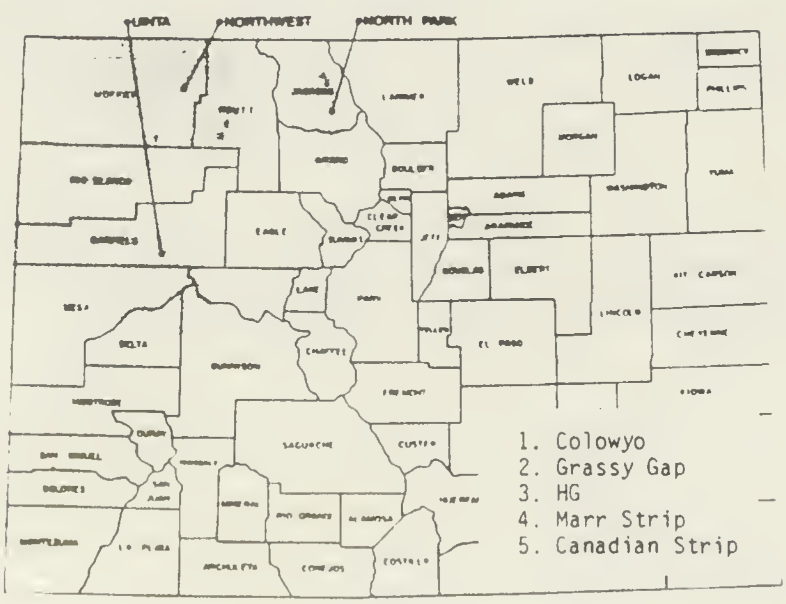

Figure 1. -- Coal Regions and Study Site Location Map

The area is characterized by gently sloping to hilly topography with elevation ranging from 1,830 to 2,290 m. (6,000-7,500 ft.). Major vegetation types are sagebrush/grass and mountain shrub. Mean annual precipitation ranges from 35 to 45 cm. (14-18 in.) with a significant portion resulting from snowfall. Mean annual temperature for Craig, Colorado 45 km. (28 mi.) northeast of the Colowyo Mine is 18° C. (42° F.).

Vegetation cover and woody density sampling was conducted by the Division in 1984, 1985, and 1989 at the Colowyo Mine on areas seeded between 1978 and 1983. Woody density only was sampled in selected designated woody plant establishment areas during 1989. Revegetation between 1978 and 1983 was limited to 3:1 (h:v) east and north facing slopes of the Streeter Canyon excess spoil fill. Since 1984, revegetation has been conducted on much gentler slopes of the backfilled pit.

Colowyo's 1978 seed mix[2] and 1982/1983 seed mix both included a large number of native and introduced grasses and forbs, and a number of native woody plants. Planting of woody plant seedlings is also a component of the revegetation program. Through 1983, seedbed preparation at Colowyo consisted of straw mulch application followed by chisel plowing and drill seeding.

Topsoil replaced on Streeter Fill reclamation areas between 1978 and 1983 was from stockpiles. Since 1985, the majority of topsoil replacement has been accomplished with direct hauling of freshly stripped soil. Replaced topsoil was a clay loam, ranging from 30 to 50 cm. (12-20 in.) in depth. Beginning in 1985, the operator established a number of 1.2-2 ha. (3-5 acre) "shrub establishment areas" within each year's reclamation. Within these areas, only shrubs and less competitive forbs have been seeded or planted in an effort to reduce woody plant competition with grasses and more competitive forbs, and to increase woody plant density and species diversity on the reclaimed lands. The shrub establishment area concept and establishment techniques are more fully discussed in Kiger, et al. (1987).

Upper Yampa River Basin

Coal mines in the Upper Yampa River Basin are concentrated primarily in that portion of the Northwest Coal Region within Routt County (Fig. 1). The area is characterized by mountainous topography with relatively steeply dipping coal seams. Mining techniques vary from 3 million ton/year single seam dragline area strip operations to 300,000 ton/year scraper/loader operations extracting up to 5 seams. Mines in this area are situated between 1980 and 2,440 m. (6,500-8,000 ft.) above sea level. Mean annual precipitation ranges from 41 to over 51 cm. (16-20 in.), a major portion of which falls as snow during the winter. Mean annual temperature in Steamboat Springs, Colorado approximately 32 km. (20 mi.) north of the mines at similar elevation is 12.1° C. (38.7° F.). Vegetation types most commonly impacted by mining are sagebrush/grass communities at lower elevations and on south slopes, mountain shrub communities at mid-elevations and aspen forest at higher elevations.

[2] Unless otherwise noted, seed mixes are not listed in this paper, but are listed in Savage and Mathews (1985).

Sampling was conducted by the Division in 1984 and 1989 at the Rockcastle Company's Grassy Gap No. 1 Mine (Grassy Gap) and in 1984, 1985 and 1989 at Yampa Mining Company's Hayden Gulch Mine (HG). The mines are located at similar elevations approximately 24 km. (15 mi.) apart. Both mines are presently inactive. Final reclamation has been completed at HG. Areas sampled at HG were seeded in fall 1981 and fall 1982. Grassy Gap sampled areas were seeded in 1978 and 1980.

Revegetation goals and techniques are considerably different at the two mines. At Grassy Gap, in conformance with the landowner's request, the revegetation plan is directed primarily toward the establishment of productive forage for livestock grazing. The seed mix used in 1978 and 1980 contained no woody species. Sampled areas were originally drill seeded in the fall. An annual stubble mulch was employed prior to seeding. Topsoil on certain portions of the reclaimed area was "live handled", though the majority of topsoil utilized was stockpiled for 1 to 3 years. At HG, a seed mix similar to the Grassy Gap mix was used in 1978 and 1980, while a more diverse mix with a higher percentage of native species, including shrubs, was utilized in 1982. The sample area seeded in fall 1981 was reclaimed with stockpiled topsoil. The sample area seeded in fall 1982 was reclaimed with "live handled" topsoil. Sampled areas were broadcast seeded, harrowed, and hydro-mulched. Measured topsoil replacement depths varied from 25 cm. (10 in.) to 46 cm. (18 in.) at Grassy Gap and from 36 cm. (14 in.) to over 50 cm. (20 in.) at HG. Soil texture ranged from silt loam to clay loam.

North Park

North Park is a high elevation intermountain park in north central Colorado bordered on the north and east by the Medicine Bow Mountains, the southeast and south by the Never Summer and Rabbit Ears Mountains respectively, and on the west by the Park Range (figure 1). The climate of North Park can be characterized as semi-arid to steppe (Griffiths 1983). Mean annual precipitation is 25 cm. (9.9 in.) with most moisture coming as thundershowers between June and September. The mean annual temperature is 2.8° C (37.1° F) and the number of frost-free days average 46. The regional vegetative community of dominance is sagebrush steppe (Kuchler, 1964), however, significant local variation is encountered and notable riparian, aspen/conifer, mountain shrub, and salt desert inclusions are found.

Revegetation was evaluated at three surface coal mining operations for this paper. The Marr Strip, permitted and operated by Kerr Coal Company and the Canadian Strip permitted by Wyoming Fuel Company were quantitatively sampled in 1984, 1985, and 1989. The Bourg Strip, permitted by Walden Coal Company was quantitatively sampled in 1989. Both the Canadian Strip and the Bourg Strip were permanently reclaimed in 1987 and 1988, respectively. The Marr Strip and the Canadian Strip are located approximately 19 km. (12 mi.) east of Walden, Colorado at an elevation of 2,469 m. (8,100') and are contiguous to each other, mining a single steeply dipping coal seam on the western side of the Johnny Moore Syncline. Mining operations began in 1974 at both mines and each utilized open pit truck and shovel (or loader) methods. The Bourg Strip is located approximately 25 km. (15 mi.) northeast of Walden, Colorado at an elevation of 2469 m. (8100'). This mine opened in 1980 and removed coal from the northwest nose of the Johnny Moore Syncline.

The area sampled at the Bourg Strip was a permanent excess spoil disposal area comprising approximately 100 ha. (40 ac). This area was reclaimed in the summer and fall of 1984. Areas sampled at the Marr Strip in 1984 were originally seeded in 1980/1981. Areas sampled in 1985 and 1989 included areas originally seeded in 1980/1981, and 1983. No perennial seeding was undertaken in 1982 at the Marr Strip. Areas sampled at the Canadian Strip in 1984, 1985, and 1989 were originally seeded in 1981 and were reseeded in 1982.

The North Park mines surveyed employed several different methods in their revegetation efforts. The Canadian Strip originally drill seeded in 1981 and reseeded using broadcast methods in 1982. The Marr Strip drill seeded all graminoids separately from shrubs and forbs in 1980, 1981, and together in 1983. Some shrubs were broadcast in 1980 at the Marr Strip. In the 1984 seeding, the Bourg Strip employed drill seeding operations for graminoids and forbs, and broadcast methods for woody plants.

Differences in method of application were largely due to equipment limitations of individual contractors employed by the mines to perform revegetation. While the Marr Strip employed an annual rye stubble mulch the season prior to perennial seeding, the Canadian Strip employed a wood chip mulch or wood chip/annual rye mulch (though this combination has been discontinued) (Stout personal comm. 1985). Straw mulch, applied at a rate of two tons/acre and crimped was used at the Bourg Strip. Measured topsoil replacement depths were 25 cm. (10 in.) at the Canadian Strip and 25 to 41 cm. (10 - 16 in.) at the Marr Strip. Topsoil replacement depths at the Bourg Strip averaged 30 cm. (12 in.). Soil textures ranged from hard packed clay to sandy loam. Seed mixes for the mines are similar in composition and emphasize planting of native grasses, shrubs, and forbs, many of which were indigenous to the area prior to mining.

METHODS AND MATERIALS

Sites were initially selected because of the age of revegetation efforts represented, geographic location, and diverse nature of the reclaimed areas.

Permit applications were reviewed and mine personnel consulted to determine areas suitable for revegetation sampling. Areas selected for sampling have all been permanently reclaimed and were at least in their second growing season (with the exception of one shrub establishment area at Colowyo).

An attempt was made to separate revegetated areas into sampling units by year, though in some instances insufficient information was present during field work and two years seedings were lumped as one treatment. Transects and quadrats were randomly located within sampling units, though a conscious effort was made to avoid "edges" near an active area or another seeding, and particularly sparse areas.

Vegetation cover was sampled by point-intercept methods. In 1984 and 1985, a mechanical 10 point frame was used while an ocular 10 point frame was used in 1989. Viert (1985) presents data documenting the comparability of mechanical and ocular point frame data, as well as the advantages in time savings and increased sampling precision associated with the ocular point frame. Field comparisons conducted by the authors in the summer of 1989 supported these conclusions.

In all three years, transects were run along a 50 m. tape. At 10 m. intervals, the point frame (10 points at 10 cm. centers) was erected and hits were recorded for plant species, litter, and bare ground. A total of 50 data points were obtained from each transect. Enough cover transects were sampled in 1985 and 1989 to achieve a 90% level of confidence with the sample mean being within 10% of the true mean. Cover sampling in 1984 was undertaken to the number of transects allowed by time constraints.

Species diversity was evaluated from the cover data by species collected on each transect. Species composition and life form were the primary components of diversity evaluated.

Woody plant density data were collected from 1 x 50 m. (1984 and 1989) or 1 x 40 m. (1985) belt transects run beside the cover transects at each sampling site. Within shrub establishment areas at Colowyo, and at the Bourg Strip, 1 x 25 m. belt transects were run due to size constraints of the area of interest or high woody plant densities. The occurrence of woody plants in each transect was tallied by species and reported in terms of number per hectare (or acre). Due to the high variability of woody plant occurrence in revegetated areas, levels of confidence comparable to those reached for cover were not achieved. However, enough samples were taken at each site to represent the densities encountered.

For each transect, a slope direction and angle were measured, and coordinates for transect orientation taken. For each revegetated area, at least one soil pit was dug to verify soil depth and texture.

Species were field identified, and voucher specimens collected where identity was in doubt. Those species in doubt were later identified at the offices of the Mined Land Reclamation Division. Nomenclature follows Harrington (1964). Vegetative sampling was conducted in August of 1984 and 1989, and July, 1985.

RESULTS

Due to the large number of tables and resulting excessive length, the Results Section of this paper could not be included in these proceedings. The Results Section is available from the authors on request.

DISCUSSION

This paper represents three seasons of data collection on revegetated sites ranging from two to eleven years in age. While the authors are confident with the accuracy of the data collected and presented, there are numerous abiotic, biotic and operational variables that have not been addressed in the design or collection of this information. For this reason, the authors caution against extrapolation of the data and our conclusions to other widely differing areas. One factor of considerable import is that growing season precipitation in 1989 was substantially below normal throughout the study region (Colorado Climate Center, 1989). Low vigor of vegetation was apparent at a number of sites and resultant early dormancy of broadleaf herbaceous plants likely resulted in those species being under represented in the data.

Axial Basin and Upper Yampa Basin

The Axial Basin and Upper Yampa Basin mine observations are discussed together due to considerable similarity with respect to environmental setting, reclamation considerations and issues of concern in the two regions.

Vegetation Cover

For the majority of the reclaimed sites observed, 1989 vegetation cover exceeded pre-mine and reference area herbaceous cover levels documented in baseline studies, despite the fact that 1989 was an abnormally dry year.

Of the two applicable reference areas at the Colowyo Mine, the highest herbaceous cover mean documented in baseline studies was 41%. In 1989, three reclaimed areas were sampled at Colowyo. The 1978 area cover mean was 41%, the 1982 area cover mean was 61.4% and the 1983 area cover mean was 48%. For the 1978 area, both vegetation cover and total ground cover (live vegetation plus litter) have remained relatively constant over the term of the study, with total ground cover estimates of 96% in both 1985 and 1989. Both vegetation cover and total ground cover have increased significantly over the term of the study for the two younger reclaimed areas.

At the HG Mine, mean herbaceous cover of the two primary vegetation types documented in the baseline study was approximately 45%. Vegetation cover values in 1989 were 50.6% and 48.2% for the 1981 and 1982 reclaimed areas, respectively. For the 1981 area, 1989 vegetation cover was similar to 1984 levels and higher than the 1985 estimate. The 1982 reclaimed area also exhibited higher vegetation cover in 1989 than in 1985. Total ground cover increased over the study term for both areas, with 1989 total cover estimates of 98.2% for the 1981 seeding and 87.2% for the 1982 seeding.

At Grassy Gap Mine, the highest pre-mine herbaceous cover mean for any vegetation type was 30%. In 1989, mean vegetation cover for the 1978 seeded area was 27.2% and mean vegetation cover for the 1980 seeded area was 38% with both values representing slight decreases compared to the 1984 data. In 1989 total ground cover was 69.9% for the 1978 reclaimed area and 80.8% for the 1980 reclaimed area. A total cover estimate was not recorded in 1984.

To summarize, vegetation cover at the three mines has remained relatively stable or increased over the study period, with some fluctuation observed. Only one site, the 1978 Grassy Gap reclaimed area would appear to be in jeopardy of failing to meet the reference area cover standard.

Species Diversity

The 1978 seeded area at Colowyo was dominated during 1984, 1985 and 1989 by three introduced grasses; intermediate wheatgrass, pubescent wheatgrass and smooth brome. Relative cover of these species increased from 78% in 1984 to 93% in 1989. No forbs were encountered in the samples in any of the sample years.

The 1982 and 1983 reclamation areas at Colowyo were seeded with a more diverse seed mix containing a slightly lower percentage of the aggressive grasses. The revegetated communities are considerably more diverse than the 1978 area, with 11 and 18 species encountered, respectively, in 1989 compared to 5 species encountered in the 1978 area. While intermediate wheatgrass has remained the dominant species in both areas, and has accounted for increasing cover percentages over the study period, several other seeded grasses and forbs have also increased or maintained their importance in the stand. In particular, cicer milkvetch, a leguminous forb, is the subdominant species in both areas and has exhibited increased cover values in each succeeding sample year. Two additional forbs were encountered during 1989 in the 1982 area and 6 additional forbs in the 1983 area. While the cover provided by forbs other than cicer milkvetch was fairly low, it is felt that this is very likely a reflection of the abnormally dry conditions at the site.

At HG, the 1981 reclaimed area was heavily dominated by smooth brome, which provided 83% relative cover in 1989. Only two other species contributed significant cover, intermediate wheatgrass and cicer milkvetch. Smooth brome had dominated the stand in previous sample years, but not to the extent observed in 1989. The 1981 reclaimed area had been broadcast seeded with a seed mix containing only six grasses and one forb and the site had received stockpiled topsoil. Only one species not included in the original seed mix, intermediate wheatgrass, was recorded in the 1989 data.

The 1982 HG reclamation exhibited markedly greater diversity than the 1981 area in both sample years. A more diverse seed mix containing 13 grasses, 5 forbs and 2 shrubs was utilized, and the topsoil was live handled rather than obtained from a stockpile. Of the 20 perennial species recorded in the 1989 data, 3 grasses, 4 forbs and 1 shrub comprising approximately 40% cumulative relative cover had not been included in the seed mix. Intermediate wheatgrass, smooth brome, Kentucky bluegrass and western wheatgrass increased in both absolute and relative cover, while perennial forb cover showed an apparent decrease between 1985 and 1989. The dominant species in 1989, accounting for 27% relative cover, was Kentucky bluegrass, a species which was not included in the seed mix.

At the Grassy Gap Mine, 1989 sampling was limited to two areas, both of which had been reclaimed using stockpiled topsoil. Both the 1978 area and the 1980 area had been drill seeded with the same seed mix, which contained 9 grasses, one forb (yellow sweetclover) and no shrubs.

Within the 1978 reclamation area, though some shifts in species rank occurred between 1984 and 1989, the major perennial grasses were the same in both years, with the exception of slender wheatgrass which provided significant cover in 1984 but was not recorded in 1989, and western and pubescent wheatgrass which were not recorded in the 1984 data but provided significant cover in 1989. Nine of the fourteen species recorded in 1989, including the only perennial forb, six perennial grasses, and two shrubs, had not been included in the seed mix. The volunteer species accounted for approximately 37% cumulative relative cover.

The 1980 reclamation area at Grassy Gap exhibited trends over the study period which were similar to the 1978 area, with certain exceptions. Big bluegrass, which had apparently decreased over the 5 year period in the 1978 reclamation, had increased in the 1980 reclamation from 10% relative cover to 34.2%. Smooth brome and intermediate wheatgrass, which had both increased in relative cover in the 1978 reclamation had decreased over the period in the 1980 reclamation. Four volunteer species including three grasses and 1 shrub accounted for approximately 21% relative cover. No forbs were represented in the 1989 cover data.

A pattern common to all of the reclaimed sites observed is that, as the stands have matured over the study period, the number of annual weeds and short lived perennial species such as mountain brome and slender wheatgrass, as well as the amount of cover contributed by such species, has declined significantly.

Smooth brome and intermediate wheatgrass, two aggressive, long lived perennial grasses have very heavily dominated certain reclaimed areas, and inclusion of these species in seed mixes appears to have the potential to limit species diversity within the seeded stands for many years, as has been previously suggested (Savage and Mathews, 1985). Of the seven reclaimed areas observed in the region, three would not currently meet approved diversity standards; the Colowyo 1978 area, due to a lack of forbs and dominance by smooth brome and intermediate wheatgrass, the HG 1981 area, due to lack of forbs and dominance by smooth brome, and the Grassy Gap 1980 area, due to lack of forbs and dominance by smooth brome and big bluegrass.

Volunteer species not included in the original seed mixes have contributed significantly to the revegetated stands in some cases, most notably the HG 1981 reclamation and the Grassy Gap 1978 reclamation. It is speculated that the volunteer component of the HG reclamation may be attributable to seed sources in the live handled topsoil, while the high percentage of volunteer species at Grassy Gap may be due in part to the relatively poor initial results obtained from the 1978 seeding, and the resultant niche space availability.

It should be noted that while, when considered individually, several of the areas exhibit very low species diversity, in actual bond release determinations such areas will most likely be included in larger reclaimed parcels made up of several reclaimed stands. This factor will mitigate to a considerable extent the effect of isolated stands dominated exclusively by one or two species. Finally, none of the reclaimed stands observed had been subjected to livestock grazing as yet, though grazing is an approved postmining use at each mine. Livestock grazing over a period of years could be expected to significantly affect the species composition of the reclaimed areas.

Woody Plant Density

At the Colowyo Mine, the operator has obtained a variance from woody plant density requirements on the steep slopes of the permanent overburden fill (1978, 1982 and 1983 reclamation areas) after concluding that shrub establishment efforts at the site were largely in vain and successfully making the case that adjacent undisturbed woody habitat would allow for wildlife to fully utilize the reclaimed areas. The most obvious impediments to shrub establishment on the fill were competition from aggressive herbaceous species (necessary to effectively stabilize soil on the site) and heavy use by deer and elk (Kiger, et al, 1987). Although woody plants were included in the seed mixes and woody seedlings were planted in the three reclaimed areas of the fill sampled by the authors in 1985 and 1989, established densities are quite low and do not appear to be increasing. Woody density for the three areas combined was 315 stems/ha (128/ac) in 1985 and 162 stems/ha (65/ac) in 1989.

In 1985, Colowyo initiated a program in which several areas from 0.5-2 hectares (2 to 5 acres) in size totalling approximately 20% of a given year's reclamation acreage are set aside as shrub establishment areas. The areas receive live handled topsoil and are broadcast seeded with a mix which contains only woody plants and non-competitive forbs, supplemented by seedling transplants. Results to date have been mixed, with some of the areas observed by the authors in 1989 characterized by fairly diverse stands of seeded forbs and shrubs, and other areas dominated almost exclusively by annual weeds after four growing seasons. The two establishment areas in which woody densities were sampled during 1989 are indicative of the wide variation observed within the establishment areas, with a mean woody density of over 35,000 stems/ha (14,170 stems/ac) in a 1988 area compared with a mean density of only 1,129 stems/ha (457 stems/ac) in a 1985 area. The reasons for the dramatic variation in woody density among the various establishment areas are not readily apparent, although some of the more promising shrub areas appeared to occupy slightly more sheltered topographic positions than the less successful areas. A longer period of time will be necessary before a meaningful assessment of the potential success of the shrub establishment area technique can be made.

At the HG Mine, moderate woody plant densities were encountered in 1985 on both the 1981 reclamation which received stockpiled topsoil and the 1982 reclamation which received live handled topsoil. Mean woody density within the 1981 reclamation area was 714 stems/ha (289 stems/ac) in 1985, compared with 1,800 stems/ha (729 stems/ac) within the 1982 reclamation area. Sampling in 1989 indicated that mean woody densities have apparently declined in both areas, to 59 stems/ha (24 stems/ac) in the 1981 area and 863 stems/ha (349 stems/ac) in the 1982 area. Snowberry was the dominant shrub by a considerable margin, accounting for 800 stems/ha (324 stems/ac) in the 1982 area. The greatest concentrations of snowberry appeared to occur along draws and swales within the reclaimed area. Chokecherry, which was fairly abundant in 1985, accounted for only 38 stems/ha (15 stems/ac) in 1989. Possible explanations for the apparent decline in woody plant density over the 4 year period include herbaceous competition, particularly for the 1981 reclamation, and heavy browsing by deer and elk, which was in evidence in both areas.

At the Grassy Gap mine, moderate numbers of woody plants, primarily big sagebrush, have become established in both the 1978 and 1980 reclaimed areas, despite the fact that woody plants were not included in the seed mix and no specific efforts were expended to reestablish shrubs. No shrubs were encountered in the 1984 sampling of the 1978 reclamation, but in 1989 an estimated density of over 800 stems/ha (324 stems/ac) was recorded. An estimated density of approximately 1400 big sagebrush stems/ha (567 stems/ac) was recorded in both 1984 and 1989 within the 1980 reclamation area. It is not readily apparent whether the volunteer sagebrush establishment resulted from a seed source in the topsoil or from wind dissemination of seed from adjacent areas. The ability of sagebrush to become established in the 1978 area over the last five years to the extent observed may be related to the comparatively low herbaceous cover levels and resultant low degree of competition provided by the seeded species.

Based on the observations at Colowyo and HG, the operators have not to date demonstrated an ability to meet the approved woody plant density standards at either operation. The approved standards are 2,470 stems/ha (1,000 stems/ac) within specified areas at Colowyo and 1,235 stems/ha (500 stems/ac) at HG. The primary establishment technique employed at the two mines is direct seeding, with a shrub establishment area program being implemented at Colowyo. Live topsoil application has been utilized at both operations. The volunteer sagebrush establishment observed at the Grassy Gap mine, where shrub establishment was not planned nor required underscores the unpredictability of shrub reestablishment.

The shrub establishment area technique being tried at Colowyo appears to hold some potential and will at the very least contribute to the body of knowledge concerning shrub reestablishment. Monitoring of the shrub establishment areas over an extended period of time will be necessary before any definite conclusions can be made.

North Park

During our sampling in 1989 it was generally noted that there was lack of maturation in seed heads for graminoid species, a lack of all growth and maturation in forb species (particularly at the Marr Strip), and a lack of new shoot meristem in woody species. We attribute this to the dry spring and summer of 1989.

Vegetation Cover

As the site with one years quantitative data, much cannot be described in terms of trends at the Bourg Strip. Several encouraging results present themselves from this reclaimed site's data. Observed vegetative cover from the site was the highest for all sites recorded in 1989. Without considering precipitation related impacts, this site's vegetative cover represents the highest value for a stand of that age over the years sampled. While drill row presence by graminoids was strong, it was observed that many of the sod-forming species had begun tillering. Similarly, bunch size had begun to increase as indicated by spread outside the drill row and litter surrounding the base.

Of the two mines in North Park where multiple year sampling occurred the Canadian Strip showed the most change in all parameters measured. Vegetative cover rose 110% over five years. The significant increase in vegetative cover is indicative of the establishment and maturing of the vegetative stand. While not quantitatively measured, the authors noted that most sod-formers had begun to tiller and spread from the original drill row patterns and the majority of bunch grasses had been present for several seasons as evidenced by the bunch size and amount of litter surround the bunch base.

When compared to the Canadian Strip over the five years sampled, the Marr Strip revegetated areas show the lowest magnitude of changes. Vegetative cover remained relatively static for the older site. Of significant note in the 1980/1981 seeding (as sampled in 1989) was the lack of forb cover. Field observations verified that the two predominant species from previous years (western yarrow and Lewis flax) had not died out, but had been severely hampered in growth by the dry conditions during the early and mid growing season. The younger site (1983 seeding) exhibited a 71% increase in cover over four years. While not specifically evaluated, it was felt that this area significantly benefited in this dry year from its gentle northerly exposure. It is postulated, that in time of environmental stress (eg low growing season precipitation) the abiotic elements will exert influence to a greater degree over the biotic community.

Species Diversity

Species numbers at the Bourg Strip are relatively low, though this may be partially explained by the small number of species in the original mix (13) as compared to the Canadian Strip (13) and the Marr Strip (24). A large similarity between species represented in cover sampling was observed at all sites in 1989. Bourg had five of seven identified species in common with both other mines, and no species were found unique to the site. While this may indicate a similarity in seed mix composition, it may also indicate a favoring of adapted species for similar sites and communities.

The rise in vegetative cover at the Canadian Strip was accompanied by a 150% rise in new species represented in the cover transects. Additional new species were represented by graminoids, forbs, and woody plants. None of the new species found were weedy or annuals, suggesting that the these colonizer type plants have been excluded form the community by competition or lack of suitable available niche space (Whittaker, 1972).

Of the new species found at the Marr Strip, the majority were first observed in 1989. Big bluegrass and Canada bluegrass were not contained in the original seed mix, yet now represent over 17% of the relative cover on the site. Big sagebrush, not encountered in the cover sampling previously, now represents nearly 5% of the relative cover. It is speculated that where seed sources are available, and a favorable place in the community exists, these niches will be filled by volunteers from nearby.

Species numbers at the Marr Strip over the period sampled remained relatively unchanged. The older seeding revealed a net decrease of species through weedy and annual species attrition. The younger seeding netted an increase in graminoids and a loss in forbs (which was discussed above). While this site has consistently shown the greatest number of species over the period observed, this may be due to the large number of species present in the seeded mix (24). In the larger, more diverse seed mix there may be an advantage, in that a greater number of species are established early. As the stand ages, species numbers may decline, but not below the number of other sites. At other sites with fewer species seeded originally, species numbers increase over time, but may be reliant on native sources for invasion.

Woody Plant Density

The most encouraging parameter (from a reclamation standpoint) was the success of woody plant seeding at the Bourg Strip. With a recorded density of 42,109 individuals/ha (16,844/ac), this operation has far exceeded the required reclamation standards of 5,000 stems/ha (2,000/ac). Casual observation within the reclaimed area did not reveal a significant density difference between the native community and the revegetated community. The main differences appear to be in age structure and plant vigor, which would be expected given the greater age and maturity of the native stands.

Woody plant densities at the Canadian Strip showed the most significant rise over the five year period monitored from no individuals found in the density quadrants to 400 individuals/ha (160/ac). While it is possible that some seed from the original planting may have germinated between 1985 and 1989, it is more likely that upwind native seed sources have been providing seed and slowly invading the site. Field observations appear to bear this out, as the age structure of individuals encountered revealed many smaller (25 cm.) plants and very few mature (|25 cm. with flower heads) individuals. While the increase of woody plants at the site is encouraging, it also illustrates the slow nature of shrub reestablishment at this site. At the stable rate of increase observed, woody plant densities would require 118 years to reach the designated success criteria of 9425 individuals/ha (3770 stems/ac).

Woody plant densities at the Marr Strip portray differing pictures. Within the 1980/1981 seeding an initial decrease between 1984 and 1985 was followed by a steady increase in density. Whether the initial decrease can be attributed to natural seedling mortality or some other factor is only speculation at this point. The 1983 seeding shows a significant decrease over the five year period. This is partially explained by the lack of two species (winterfat and Woods rose) which comprised 40% of the individuals originally encountered. Additionally, big sagebrush decreased 22% during this period. Speculation on the cause of this decrease could include seedling mortality, drought, and community differentiation due to abiotic factors. At this point we can provide no substantiated explanation.

CONCLUSION

The difficulties and uncertainties regarding woody plant reestablishment appear to present the primary obstacle to meeting regulatory requirements for revegetation success in the study areas. Although some promising results have been obtained, a consistent pattern of success has not been demonstrated. Further investigation of new establishment techniques and dynamics of woody plant communities would appear to be necessary to enable operators to meet current woody plant density standards within the minimum 10 year bond liability period.

Although a few of the sampled stands were heavily dominated by a small number of species, the majority of the sites exhibited diversity levels approaching or exceeding the approved standards. In general, it appears that relatively diverse seed mixes containing small quantities of aggressive perennial grasses such as smooth brome and intermediate wheatgrass have resulted in more diverse revegetated communities than simpler mixes dominated by the aggressive grasses. Volunteer species originating from seed sources in the topsoil or adjacent undisturbed areas contributed significantly to stand diversity at several sites.

With very few exceptions, satisfactory levels of herbaceous cover have been established on the reclaimed areas observed, with little or no evidence of active erosion. Weedy and annual species have been largely excluded from revegetated stands within 5 years after initial seeding.

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PLANT SPECIES ESTABLISHMENT FOR RECLAMATION PURPOSES ON FOUR SOILS AT THE LA PLATA MINE IN NORTHWESTERN NEW MEXICO

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ABSTRACT

In the fall of 1981, 25 species of grasses, forbs , and shrubs were individually planted on 3.5 x 3.5 m plots. Each plot was replicated four times on each of four different soils. The four soils included 1) a graded spoil covered with topdressing removed from a native site dominated by greasewood, 2) a graded spoil covered with topdressing removed from a native site dominated by sagebrush, 3) a graded spoil covered with topdressing removed from a mixture of greasewood and sagebrush dominated sites, and 4) graded spoil with no topdressing.

Seeding cool season grasses gave high cover percentages except with Indian ricegrass. Seeding warm season grasses resulted in low cover. Mixing greasewood and sagebrush derived topdressing gave an overall additive effect to cover that was often similar to cover on sagebrush derived soils. Seeding spoil with grasses gave low percentages of cover. Forb cover was at or near zero and not considered successful when planted as a monoculture. Cover of seeded shrubs was high for fourwing saltbush and shadscale while all other shrubs had lower cover.

Seeding cool season grasses gave high densities while seeding warm season grasses gave low densities except with alkali sacaton and galleta in mixed topdressing. Mixing greasewood and sagebrush derived topdressing gave a synergistic effect to grass density. Densities of forbs were 2.2 plants M^{-2} for yellow and white sweetclover while other species were at or near zero. Density of seeded shrubs was high for fourwing saltbush, shadscale, and winterfat. Other species had low densities. Mixing topdressings did not give added benefits to shrub density.

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INTRODUCTION

In January, 1981, Utah International purchased a 1,200 hectare lease north of La Plata, New Mexico, with the intent of eventually strip mining coal. To receive a permit to mine, Utah International had to provide a reclamation plan documenting the steps it would take to successfully reclaim the La Plata lease. The proper selection of plant species is critical to successful reclamation. Revegetation provides ground cover, reduces erosion, and should provide a sustainable rangeland.

Plant species used for reclamation must be selected on the basis of their adaptation to the region and to post-disturbance site conditions. They should also be selected in accordance with land management goals, and meet regulatory requirements. Summaries of plant species trials for reclamation can be used as guidelines for the selection of a proposed seed mixture. Research can evaluate the establishment and survival of these species to post-disturbance conditions.

The purpose of this study was to evaluate the establishment and survival of 25 species of grasses, forbs, and shrubs planted in 1981.

METHODS

Site Description

Climate of the La Plata lease is semi-arid, characterized by low humidity, infrequent precipitation, intense solar radiation and large annual and diurnal temperature variations. Light to moderate winds occur during most periods of the year with strong winds common in the spring. Seasonal distribution of precipitation is divided into a wet season from July through October, and a drier season from November through June. Summer precipitation usually results from convective thunderstorms which are intense and of short duration. Frontal storms occur during the winter. Mean annual precipitation is about 240 mm with a range from 150 to 450. Elevation ranges from 1719 to 1938 m. Characteristics of the four different soils used as topdressing in this study are shown in table 1.

Plot Preparation

A 1.4 ha site within the La Plata lease was cleared of vegetation and soil, and leveled leaving an exposed surface of spoil. Four different topdressings were randomly laid in 32 x 20 m blocks on top of spoil. There were four blocks for each topdressing. The four topdressings included 1) topdressing from a greasewood dominated community originally located on lowland alluvium, 2) topdressing from a sagebrush dominated community originally located on uplands, 3) a mix of topdressing (1:1) from

the sagebrush and greasewood communities, and 4) spoil material. Mean topdressing depth was 21 cm, with a standard deviation of 3 cm.

Planting

Each soil block was divided into 36 plots, each 3.5 x 3.5 m with a 0.5 m buffer zone. From October 12-19, 1981, 25 plots per block were uniformally broadcast seeded with one species per plot at a rate of 615 pure live seeds m^{-2}. Plots were raked to cover seed and mulched with straw at a rate of 2,270 kg ha^{-1}. The straw was crimped with a Finn Crimper. The entire study area was surrounded with a 2.5 m high fence to exclude ungulates.

The following list of plants with their respective habits, common names, scientific names, and symbols were planted on the site:

Habit	Common Name	Scientific Name	Symbol
Grass	Crested wheatgrass	*Agropyron cristatum*	Agcr
	Desert wheatgrass	*Agropyron desertorum*	Agde
	Streambank wheatgrass	*Agropyron riparium*	Agri
	Western wheatgrass	*Agropyron smithii*	Agsm
	Pubescent wheatgrass	*Agropyron trichophorum*	Agtr
	Russian wildrye	*Elymus junceus*	Elju
	Indian ricegrass	*Oryzopsis hymenoides*	Orhy
	Sideoats grama	*Bouteloua curtipendula*	Bocu
	Blue grama	*Bouteloua gracilis*	Bogr
	Galleta	*Hilaria jamesii*	Hija
	Alkali sacaton	*Sporobolus airoides*	Spai
	Sand dropseed	*Sporobolus cryptandrus*	Spcr
Forb	Lutana cicer milkvetch	*Astragalus cicer*	Asci
	Tahoka daisy	*Aster tanacetifolia*	Asta
	California buckwheat	*Eriogonum fasciculatum*	Erfa
	White sweetclover	*Melilotus alba*	Meal
	Yellow sweetclover	*Melilotus officianale*	Meof
	Palmer penstemon	*Penstemon palmeri*	Pepa
	Globemallow	*Sphaeralcea ambigua*	Spam
Shrub	Fourwing saltbush	*Atriplex canescens*	Atca
	Shadscale	*Atriplex confertifolia*	Atco
	Winterfat	*Ceratoides lanata*	Cela
	Curlleaf mountain mahogany	*Cercocarpus ledifolius*	Cele
	Pinyon pine	*Pinus edulis*	Pied
	Bitterbrush	*Purshia tridentata*	Putr

Cover

Cover data (aerial cover of living plant material) by species were sampled in mid-August, 1988 on each seeded species plot utilizing three randomly located 3-m line intercept

transects. Continuous readings were taken to the nearest millimeter along the entire length of the transect. The transect was located by dividing the plot into a grid at intervals of 1 decimeter and choosing a point from a random numbers table (the same points were used on all species plots). The 0.5 m buffer zone was left around the edge of each plot. Cover data were collected for cool season grasses and for warm season grasses, forbs, and seeded shrubs.

Density

Density data were collected to evaluate emergence of each species. Density (number of live plants per unit area) used three random 50 x 100 cm quadrats per species in 1988.

Statistical Analysis

All vegetation data (cover and density) were analyzed using a randomized block analysis of variance. In cases where there were significant F-values, a least significant difference test (LSD) was performed at the 0.05 level of probability. The valid application of tests of significance in the analysis of variance requires that experimental errors be independently and normally distributed with a common variance. However, for most types of biological data, Steel and Torrie (1980) conclude that disturbances resulting from failure of the data to fulfill the above requirements are unimportant. However, Steel and Torrie (1980) also point out that discrete data should be examined to ascertain whether or not there is a correlation between the treatment means and their within-treatment variances. They conclude if the variation shows little change, the value of any transformation will be doubtful.

Therefore, various data were examined using the following formula:

$$t = \frac{r}{((1-r^2)/n-2)^{-2}}$$

where r is the correlation coefficient for the correlation between treatment and their within-treatment variance, and n equals the number of samples (Steel and Torrie 1980). The t-values indicate if a transformation of the data was needed.

RESULTS

When reporting and interpreting the results, the terms "synergistic," "additive," and "antagonistic" are sometimes used. When two soils are combined and the results are equal to the same of either soil, the soil combination is said to be additive. When a greater response occurs than either soil individually, then the soil combination is said to by synergistic. When a smaller response occurs than either soil individually, then the soil combination is said to be antagonistic.

Cover

Grasses

Table 2 shows the mean percentage cover for the 12 grass species seeded on the four different soils 7 years (1988) after seeding. With all species combined, the most cover was on sagebrush derived and mixed topdressings (1.7% each) while the lowest was on greasewood derived topdressing and spoil (0.9% each). With all soils combined, cover of the cool season species ranged from <0.1 to 3.3% with the greatest being crested wheatgrass. The warm season grasses ranged from 0.1 to 2.2% with all soils combined. Most of these plants in 1988 were mature bunchgrasses. Overall, mixing the soil was additive with an increase in the amount of cover compared to greasewood derived soils.

<u>Greasewood derived topdressing</u> By 1988 desert wheatgrass had the most cover (3.9%) which was not significantly different from crested wheatgrass (3.3%). All the other grasses were 1.0% or less. This shows how crested and desert wheatgrasses sustained a high percentage of cover on this soil.

<u>Sagebrush derived topdressing</u> By 1988 alkali sacaton had the most cover (3.8%). It is not known how long it took to achieve this much cover. This is the only warm season grass that was as successful as the cool season grasses. The cover of cool season grasses ranged from 0.1 to 3.4% with all but one species being 1.7% or more. The cool season species with the most cover were pubescent wheatgrass and Russian wildrye cover of warm season grasses ranged from 0.0 to 3.8% with all but one species being 0.4% or less.

<u>Mixed topdressing</u> By 1988, crested wheatgrass had the highest cover (6.1%). While crested wheatgrass experienced a synergistic effect from mixing topdressings, the other cool-season species' results were additive. The warm season grasses increased somewhat up to 1.1% for blue grama.

<u>Spoil</u> By 1988, overall cover values were low with the highest being 4.1% for alkali sacaton. Russian wildrye had 2.1% while all the others were 1.0% or less.

Forbs

In 1988 cover values for forbs ranged from 0 to 0.4% with no significant differences. Generally, the cover is too low to evaluate the effects of the various topdressing treatments.

Shrubs

Table 3 shows mean percentage cover for the six seeded shrubs on the four different soils. With all species combined, the most cover was on greasewood followed by sagebrush derived topdressing. Mixing the topdressings had an antagonistic

effect.
Even the spoil had more mean shrub cover than the mixed topdressing. Across all soils, fourwing saltbush had the most cover (9.2%) followed closely by shadscale (7.0%). The other species had less than 1.5% across all soils.

<u>Greasewood derived topdressing</u> By 1988, fourwing saltbush and shadscale had covers of 14.8 and 16.3%, respectively while the other species were 1% or less.

<u>Sagebrush derived topdressing</u> Fourwing saltbush had a large amount of cover on this soil while covers of shadscale, winterfat, and bitterbrush were also high enough to be meaningful.

<u>Mixed topdressing</u> Mixing topdressing resulted in much lower cover for fourwing saltbush and shadscale. Winterfat cover was not lower on this soil than on sagebrush derived topdressing. The other species were very low.

<u>Spoil</u> Cover was quite high for fourwing saltbush and shadscale with curlleaf mountain mahogany being successful only on this soil. Only winterfat had no cover.

Density

Grasses

In the Intermountain Region, artificial seeding rather than natural revegetation has been recommended where there is less than one desirable bunchgrass to every square meter or one stem of western wheatgrass or other sodforming, desirable plants to every one and a half square meters. On foothill sagebrush range, a minimum of one desirable grass plant for each half meter or a 15% ground cover of desirable perennial grasses has been used as an index for successful recovery possibilities without artificial seeding. The desired density after successful seeding is less defined and depends on site potential and management goals.

Tables 4 shows the mean density for the 12 grasses seeded on the four different soils after 7 years (1988). With all species combined, the most grasses were on the mixed topdressing (13.5 grasses m^{-2}) while the lowest was on the greasewood derived topdressing. Apparently, mixing the other two soils had a synergistic effect on grass density. With all soils combined, density of the cool season grasses ranged from 0.7 to 40.4 plants m^{-2} with the greatest being western wheatgrass. This species exhibited the greatest ability by far to spread into areas that had not been seeded or had been seeded with other species. The warm season grasses ranged from 0.3 to 3.5 plants m^{-2} with all soils combined. Most of these plants in 1988 were mature bunchgrasses. Overall, mixing the soil helped increase the density compared to greasewood derived soils. This is a conclusion similar to that for cover.

<u>Greasewood derived topdressing</u> By 1988, western wheatgrass was the most dense (19.3 plants m^{-2}) cool season grass and was similar

to crested wheatgrass, desert wheatgrass, and Russian wildrye Streambank wheatgrass, pubescent wheatgrass, and Indian ricegrass densities were not significantly greater than the warm season grass species which had no density.

Sagebrush derived topdressing By 1988, western wheatgrass had the most density (49.2) and was significantly greater than all other grasses with crested wheatgrass being the next most dense with 16.5 plants m^{-2}. This great difference is not manifested in cover because western wheatgrass is far less robust than the other seeded grasses. Indian ricegrass, sideoats grama, blue grama, and sand dropseed have densities low enough to qualify for reseeding.

Mixed topdressing By 1988 western wheatgrass had the most density (63.2) which was significantly greater than all other species within this soil and the highest of any species within any soil The other cool season species had from 13.2 to 19.2 plants m^{-2} except Indian ricegrass. Galleta was more dense on this soil than any other (6.0) and alkali sacaton was very abundant (10.2 plants m^{-2}).

Spoil By 1988 western wheatgrass had the most density (30.0). Except for Indian ricegrass, the other cool season grasses were abundant and ranged from 3.5 to 17.5 plants m^{-2}. Galleta had 2.2 plants m^{-2} but the other warm season species were marginal (0.0 to 1.5).

Forbs

By 1988, forbs were scarce. Yellow and white sweetclover densities were each 2.2 plants m^{-2}. All other species were less than 2.2 and not significantly different. It is not known how many of the seedlings became established or how long they persisted.

Shrubs

Table 5 shows the mean density for the six shrubs seeded on the four soils after 7 years (1988). With all species combined, the most shrubs were found on the greasewood derived soils which were about 2.5 times as dense as the other soils. With all soils combined, fourwing saltbush had the greatest density followed by winterfat and shadscale.

Greasewood derived topdressing By 1988, the only species found on this soil were fourwing saltbush (9.7), shadscale (2.7), and winterfat (3.5 plants m^{-2}). When the fourwing saltbush density (9.7 plants m^{-2}) is not significantly different from zero then it is obvious that much variation exists within the species that were present on this soil.

Sagebrush derived topdressing By 1988 only winterfat (2.8 plants m^{-2}) had significantly more density than the absent species. The species that are associated with sagebrush on undisturbed

native sites were not found.

Mixed topdressing By 1988, winterfat was still the most abundant species (3.2). Densities of the other shrubs were marginally satisfactory. Only winterfat and fourwing saltbush had more than 1 plant m^{-2}.

Spoil By 1988, three shrubs had densities greater than 1 plant m^{-2}. These included bitterbrush (2.2), shadscale (2.0), and fourwing saltbush (1.2 plants m^{-2}).

SUMMARY AND CONCLUSIONS

Seeding cool season grasses gave high cover percentages except with Indian ricegrass. Seeding warm season grasses gave low cover percentages. Mixing greasewood and sagebrush derived topdressing gave an overall additive effect to cover. Seeding spoil with grasses gave low percentages of cover. Cover of seeded forbs was at or near zero. Cover of seeded shrubs was high for fourwing saltbush and shadscale. Other shrub species had low cover percentages.

Seeding cool season grasses gave high densities. Seeding warm season grasses gave low densities except with alkali sacaton and galleta in mixed topdressing. Mixing greasewood and sagebrush derived topdressing gave a synergistic effect to density. Density of forbs was 2.2 plants m^{-2} for yellow and white sweetclover but at or near zero for all other species. Density of seeded shrubs was high for fourwing saltbush, shadscale, and winterfat. Other species had low densities. Mixing topdressings did not give added benefits.

Table 1. Mean soil characteristics[1] for each of the four different soils.

Soil characteristic	Greasewood derived topdressing	Sagebrush derived topdressing	Mixed topdressing[2]	Spoil
Sand (%)	44	46	48	39
Silt (%)	33	25	28	24
Clay (%)	23	29	24	37
Saturation (%)	40.0	41.8	41.6	65.0
pH	8.0	7.7	7.6	7.4
Electrical conductivity (mmhos cm^{-1})	2.2	0.7	1.2	3.3
Na (meq l^{-1})	17.1	1.2	5.3	13.1
Ca (meq l^{-1})	3.4	4.1	5.1	9.0
Mg (meq l^{-1})	1.2	1.6	2.2	12.8
Sodium absorption ratio	13.4	0.7	3.3	3.8
N (meq l^{-1})	14.4	7.4	9.8	6.5
P (meq l^{-1})	5.8	3.2	6.6	3.0
K (meq l^{-1})	171	198	184	76

[1] Soil samples were collected and analyzed in August, 1988. Each mean represents a composite sample from 0-10 depth.

[2] The mixed topdressing is a 1:1 mix of topdressing from the greasewood and sagebrush plant communities.

Table 2. Mean percentage cover[1] for 12 grasses seeded on four different soils.

Species	Habit	Greasewood derived topdressing	Sagebrush derived topdressing	Mixed topdressing[2]	Spoil	Mean
Agcr[3]	cs[4]	3.3 a	2.9 ab	6.1 a	1.0 bc	3.3
Agde	cs	3.9 a	1.7 bc	2.6 bc	0.6 bc	1.9
Agri	cs	1.0 b	2.2 ab	1.5 b-e	0.6 bc	1.3
Agsm	cs	0.5 b	2.8 ab	2.4 bc	1.0 bc	1.7
Agtr	cs	0.4 b	3.3 ab	2.3 bcd	0.2 bc	1.6
Elju	cs	1.0 b	3.4 ab	2.8 b	2.1 b	2.3
Orhy	cs	0.0 b	0.1 cd	0.1 e	0.0 c	<0.1
Bocu	ws	0.0 b	0.2 cd	0.0 e	0.0 c	<0.1
Bogr	ws	0.0 b	0.2 cd	1.1 b-e	0.5 bc	0.4
Hija	ws	0.0 b	0.4 ced	0.6 cde	0.2 bc	0.3
Spai	ws	0.7 b	3.8 a	0.3 de	4.1 a	2.2
Spcr	ws	0.0 b	0.0 d	0.0 e	0.4 bc	0.1
Mean		0.9	1.7	1.7	0.9	1.3

[1]Cover data were collected in mid-August, 1988. Any means with the same letter within a soil are not significantly different at the 0.05 probability level.

[2]The mixed topdressing is a 1:1 mix of topdressing from the greasewood and sagebrush plant communities.

[3]Agcr=crested wheatgrass, Agde=desert wheatgrass, Agri=streambank wheatgrass, Agsm=western wheatgrass, Agtr=pubescent wheatgrass, Elju= Russian wildrye, Orhy=Indian ricegrass, Bocu=sideoats grama, Bogr= blue grama, Hija=galleta, Spai=alkali sacaton, and Spcr=sand dropseed.

[4]cs = cool season ws = warm season

Table 3. Mean percentage cover[1] for six seeded shrubs on four different soils.

Species	Greasewood derived topdressing	Sagebrush derived topdressing	Mixed topdressing[2]	Spoil	Mean
Atca[3]	14.8 ab	14.3 a	2.3 abc	5.6 a	9.2
Atco	16.3 a	3.3 a	2.9 a	5.4 a	7.0
Cela	0.7 bc	2.3 ab	2.4 ab	0.0 a	1.4
Cele	0.0 c	0.0 b	0.0 c	2.3 a	0.6
Pied	0.0 c	0.0 b	0.0 c	0.3 a	0.1
Putr	0.0 c	2.5 ab	0.2 bc	1.4 a	1.0
Mean	5.3	3.7	1.3	2.5	

[1]Cover data were collected in mid-August, 1988. Any means with the same letter within a soil are not significantly different at the 0.05 probability level.

[2]The mixed topdressing is a 1:1 mix of topdressing from the greasewood and sagebrush plant communities.

[3]Atca=fourwing saltbush, Atco=shadscale, Cela=winterfat, Cele= curlleaf mountain mahogany, Pied=pinyon pine, and Putr=bitterbrush.

Table 4. Mean density[1] (number of live plants m^{-2}) for 12 grasses seeded on four different soils.

Species	Habit	Greasewood derived topdressing	Sagebrush derived topdressing	Mixed topdressing[2]	Spoil	Mean
Agcr[3]	cs[4]	13.2 a	16.5 b	14.2 bc	6.0 bc	12.5
Agde	cs	13.4 a	14.5 b	13.2 bc	9.8 bc	12.7
Agri	cs	2.3 b	11.5 b	19.2 b	17.5 b	12.6
Agsm	cs	19.3 a	49.2 a	63.2 a	30.0 a	40.4
Agtr	cs	0.2 b	6.0 b	15.5 bc	3.5 c	6.3
Elju	cs	11.9 a	15.8 b	14.2 bc	8.8 bc	12.7
Orhy	cs	0.2 b	0.5 b	2.2 c	0.0 c	0.7
Bocu	ws	0.0 b	0.2 b	1.0 c	0.0 c	0.3
Bogr	ws	0.0 b	0.2 b	2.2 c	1.0 c	0.8
Hija	ws	0.0 b	3.2 b	6.0 bc	2.2 c	2.8
Spai	ws	0.0 b	2.2 b	10.2 bc	1.5 c	3.5
Spcr	ws	0.0 b	0.5 b	0.8 c	1.2 c	0.6
Mean		5.1	10.0	13.5	6.8	8.8

[1]Density data were collected in mid-August, 1982. Any means with the same letter within a soil are not significantly different at the 0.05 probability level.

[2]The mixed topdressing is a 1:1 mix of topdressing from the greasewood and sagebrush plant communities.

[3]Agcr=crested wheatgrass, Agde=desert wheatgrass, Agri=streambank wheatgrass, Agsm=western wheatgrass, Agtr=pubescent wheatgrass, Elju= Russian wildrye, Orhy=Indian ricegrass, Bocu=sideoats grama, Bogr= blue grama, Hija=galleta, Spai=alkali sacaton, and Spcr=sand dropseed.

[4]cs = cool season ws = warm season

Table 5. Mean density[1] (number of live plants m^{-2}) for six shrubs seeded on four different soils.

Species	Greasewood derived topdressing	Sagebrush derived topdressing	Mixed topdressing[2]	Spoil	Mean
Atca[3]	9.7 a	2.2 ab	1.2 b	1.2 a	3.6
Atco	2.7 a	1.2 ab	1.0 b	2.0 a	1.7
Cela	3.5 a	2.8 a	3.2 a	0.8 a	2.6
Cele	0.0 a	0.0 b	0.2 b	1.0 a	0.3
Pied	0.0 a	0.0 b	0.0 b	0.0 a	0.0
Putr	0.0 a	0.0 b	1.0 b	2.2 a	0.8
Mean	2.6	1.0	1.1	1.2	

[1]Density data were collected in mid-August, 1988. Any means with the same letter within a soil are not significantly different at the 0.05 probability level.

[2]The mixed topdressing is a 1:1 mix of topdressing from the greasewood and sagebrush plant communities.

[3]Atca=fourwing saltbush, Atco=shadscale, Cela=winterfat, Cele= curlleaf mountain mahogany, Pied=pinyon pine, and Putr=bitterbrush.

Planning, Rehabilitation and Treatment of Disturbed Lands
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VEGETATION ASSOCIATED WITH THE MAJOR SOILS AND RECLAMATION AREAS ON THE NAVAJO MINE, NEW MEXICO

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ABSTRACT

Mine-land reclamation success is usually measured by comparing reclaimed areas to the pre-mined or native conditions. Establishing standards of reclamation is made more difficult when the native conditions are extremely variable as for the Navajo Mine. The Navajo mine lease has annual grazing capacities ranging from 12 hectares (30 acres) to 80 hectares (200 acres) per sheep. The objective of this research was to determine the vegetal characteristics combining the most extensive or most productive native soil types on the Navajo Lease. Then to compare these data using weighted means (based on percent area) to the vegetal characteristics of topdressed and non-topdressed reclamation plots. Some native areas have high cover, shrub density and phytomass. However, these vegetal characteristics are lower for the average native condition than the average for either the topdressed or non-topdressed reclamation plots. The weigthed mean of the native areas is low because of the extensive amount (>65%) of badland and natrargid type soils. These two mapping units have extremely low cover, shrub density and phytomass. Reclaimed plots without topdressing have higher cover and phytomass than topdressed reclamation plots. This is because of the high shrub density. However, the topdressed reclamation areas produce more perennial forbs and grasses than non topdressed plots. This is considered to be more desirable for reclamation success.

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INTRODUCTION

The Navajo Mine, the largest surface coal mine in New Mexico is located on the Navajo Indian Reservation in the Four Corners region of New Mexico. The mine was dedicated in 1963 and now includes some 12,700 hectares (31,400 acres) of land leased from the Navajo Nation by BHP-Utah International, Inc. Coal reserves are estimated to be about 1.1 billion metric tons. This mine delivers approximately 7 million metric tons of coal each year. Mine operations are conducted to minimize the amount of land disturbed, and then to restore that land to a condition equal to or better than the conditions prior to mining. It is the objective of the mine to produce coal for use as energy and being good stuarts of the environment before, during and after mining.

The first physical step in any new mining area involves saving topdressing suitable for reclamation when present. The topdressing is mapped, evaluated, removed and stockpiled. After the topdressing is removed, the overburden or waste material above the coal seams are drilled, blasted and stripped. Each strip is about 30 meters (100 feet) wide and 1.5 to 4.5 km (1 to 3 miles) long. The overburden is removed by use of 30 to 38 cubic meter (40 to 50 cubic yard) capacity draglines. The coal is removed and overburden (spoil) is placed back into the pit and graded to a gently rolling topography that resembles the pre-mine landscape. After grading, the spoil material is covered with about 15 cm (6") of topdressing. Topdressing has been required for reclamation of areas mined after 1978.

These reclamation plots are seeded with mixtures consisting of various species of grasses, forbs and shrubs, most of which are native. After seeding, the area is mulched with straw at a rate of about 3.4 metric tons per hectare (1.5 tons per acre) and crimped. Irrigation is used to supplement natural precipitation during plant establishment. Reclaimed areas are irrigated frequently during germination and infrequently after emergence through late summer. Total water application amounts to about 380 mm (15 inches). An early spring irrigation is applied the following year to complete the revegetation program. During subsequent years, the vegetation maintains itself with only natural precipitation. Reclamation began in 1975 and has continued to the present date.

To establish a standard for reclamation achievement, the natural environment is assessed to determine conditions prior to mining. Every year, a range survey is conducted on the undisturbed areas of the lease. This region has a long history of severe overgrazing by livestock especially sheep that has eliminated many of the better, palatable plant species. Some small areas are still somewhat productive but only support about one sheep for every 12 to 20 hectares (30

to 50 acres). However, this is considered good when compared with a typical badlands area (exposed weathered shale) where the plant cover averages far less than 1%. Much of the lease was originally badlands that was naturally in an unproductive state. In these areas well over 80 hectares (200 acres) are needed to feed one sheep.

Annual evaluations of native areas show some are quite productive while other areas are barren. The most productive areas are in the soil mapping units, Shiprock & Razito. These are the least extensive (less than 5%) across the lease. In contrast, the least productive areas; such as the badlands and natrarigids, are the most extensive (65%). Reclaim success could be compared to a single productive mapping unit, but a more valid comparison is to determine the weighted average of the native area productivity for the entire lease.

The objectives of this study are:

1. to compare vegetal characteristics associated with native and reclaimed areas at the Navajo mine.

2. to compare vegetal characteristics associated with topographic positions for areas reclaimed with and without topdressing at the Navajo mine.

SITE DESCRIPTION AND SELECTION

The Navajo Mine is located within the Colorado Plateau physiographic province which has within its borders a wide diversity of topography, geologic materials, soils and vegetation. The general terrain of the Navajo Mine is characterized by rough and broken topography, badlands, plateaus and mesas, intermingled with escarpments and valleys or washes. Many of the soils are formed from alluvium and eolian sediments derived from shale and sandstone. Some soils have formed from residium. Most of the soils in the survey area have been forming only since the late-Pleistocene and during the Holocene. It is every common to find buried soils that date back to the Pleistocene.

Annual precipitation averages 155 mm with large annual differences. Snowfall may occur from November to April and snow depth averaged 230 mm each year. The temperature is typical of continental areas, rarely exceeding 38°C with few days of temperatures below -18°C. The average daily range of temperature is 21°C.

The study sites were selected to represent the most common landscapes of either native or reclaimed areas. Six natives areas were selected from the Soil Resources of the Navajo Mine, a soil survey of the mine lease. The six native areas were identified as soil mapping units and include badlands

(32.9% of mine lease), Bacobi and Monierco (7.4%), Farb and Persayo (3.4%), natrargids (32.1%), Razito (2.1%), and Shiprock (0.6%). These total 78.5% of the mine lease and represent the most extensive or most productive soil mapping units. Fifteen reclaimed areas were chosen. These areas have been reclaimed for at least 10 years included topographic positions of backslopes and swales. Vegetal transects were randomly located in the immediate proximity of soil profile locations used to characterize the soil type. Soil laboratory data from the soil survey were used to characterize the native soils. One profile at least two meters (6 feet) deep dug in each of the reclaim areas to characterize the soil. The soils data is not included in this paper.

METHODS

Vegetal Cover

Vegetal cover by species for grasses, forbs and shrubs was determined by utilizing ten 30-meter line intercept transects on each of six native sites and ten transects in each topographic position for the fifteen reclaimed sites in the summer of 1989. The transects were placed on ten reclaimed sites without topdressing six in backslope topographic positions and four in swales. Transects were placed on five reclaimed sites with topdressing, three backslopes and two swales positions. Continuous readings, recording intercepted length of live vegetation were taken along the entire length of the transect. For all native and reclaimed sites, a total of 210 transects were located. The intercepted length of each plant was recorded as a percentage. This value was converted to a total weighted mean for the six native areas and the fifteen reclaimed areas by topdressing treatment and topographic position.

Shrub Density

Density for shrubs was determined from counting the number of rooted individuals by species within 1 meter of either side of the 30 meter transects. This value was converted to total number across the six native mapping units or reclaimed areas.

Phytomass

Dry weights of grasses, forbs and shrubs were harvested by species within a 10 cm x 10 m quadrate (1 m^2). The longest edge of the quadrate was placed to the right of and adjacent to a previously selected random location along the 30 meter tape. All phytomass within the vertical projection of the quadrate was clipped regardless of rooting location. The clipped plants were air dried in an oven at 60°C to a constant weight and recorded to the nearest one hundredth gram. These values were converted to total phytomass across the six native mapping units or reclaimed areas.

RESULTS

Vegetal Cover

The most cover was found on the Razito mapping unit (3.99%), but this site only makes up 2.1% of the lease. The least amount of cover was on the badlands and natrargids, where no perennial plants were found. Badlands had 0.8% and, natrargids had 0.4% annual cover. When cover for each native site is multiplied by the percentage of area associated with the mapping unit, the mean cover for pre-mined conditions can be calculated, Table 1. An example is Razito which has a high percentage of cover but comprises a small area, so that its cover contribution to the entire lease is quite small. When all six sites, are included the overall mean was only 0.57% for native areas. Nearly half of this cover was annuals with perennial forbs and grasses contributing less than a fifth of the total cover.

The reclaimed spoil sites without topdressing had the most total cover of all sites (5.65% on backslopes and 8.83% on swales). Nearly all of this cover (5.39% on backslopes and 7.92% on swales) was shrubs, mostly fourwing saltbush with some broom snakeweed. When the two topographic positions are reported by percentage of area (Table 1), total cover of perennial plants is more than ten times greater than the native sites. Perennial forbs and grasses comprise a very small part of the total cover on sites without topdressing although it is more than twice that found on native sites. A high percentage of lower seral stage annuals were present (0.97%).

The reclaimed spoil sites with topdressing had three times as much total cover as the native sites (1.70% versus 0.57%), Table 1. The majority of this total cover was perennial forbs and grasses with only a small amount of annuals. The ratio of 2:1 cover for perennial grasses and forbs versus shrubs is considered to be more ideal than a higher percentage of shrubs. A grass dominated savanna has more site stability, less interspecies competition, less runoff, less erosion and more annual production than a brush dominated rangeland. Therefore, mining the areas covered by these six native sites and then reclaiming them with the mean success of the present programs results in a significant improvement in cover and species mix.

Shrub Density

The greatest shrub density was found on the Razito mapping unit (27,384 shrub ha^{-1}), but this site only makes up 2.1% of the lease. This is fortunate because 21,617 of these shrubs are the poisonous broom snakeweed. Other shrubs on this site

with their proper use factors for sheep include: fineleaf yucca (5%), plains pricklypear (0%), slender eriogonum (15%), Mormon tea (30%), green (0%) and rubber rabbitbrush (15%), fourwing saltbush (50%) and silvery wormwood (30%). Badlands and natrargids had no shrubs. When shrub density for each native site is multiplied by the percentage of area associated with the mapping unit, the total number for all sites can be calculated, Table 2. Including all six sites gave an overall total of about 5 million shrubs, half of which are broom snakeweed and only 78 thousand or 1.6% are the highly desirable fourwing saltbush.

The reclaimed spoil sites without topdressing had the most shrubs, most of which were fourwing saltbush. This site also had about 2% broom snakeweed. Other species included some shadscale, mound scale, green rabbitbrush, and fineleaf yucca. When the six native areas, 3,457 hectares are reclaimed without topdressing, the result is 10,846,338 total shrubs which is more than twice the number before mining, Table 2. Nearly all of this is fourwing saltbush, which is the only species of shrub found in the swales.

The reclaimed spoil sites with topdressing had more shrubs than the native areas (5,622,119 versus 5,009,712), but the densities were not markedly different. None of these on topdressed areas were broom snakeweed. A large portion were species other than fourwing saltbush which leads to site diversity and ecological stability. Other species included significant amounts of shadscale (25%) plus mound scale and broadscale. Although there are not as many shrubs when reclaimed with topdressing as without topdressing, these results are considered a more desirable mixture. This density of shrubs represent 1 shrub per 2.5 m (8.2 feet). At this density, shrubs are not considered to be dominating the site at the expense of the grass/forb understory.

Phytomass

The greatest phytomass on the native sites was found on the small area called the Razito mapping unit (22 kg ha^{-1}). There was no perennial phytomass on the extensive badlands and natrargids. The phytomass across all native sites was only 89 tons with 68 tons or 76% being perennials, Table 3. This is equivalent to 0.023 tons or 23 kg ha^{-1} (20.5 lbs. acres $^{-1}$).

The reclaimed spoil sites without topdressing had the most phytomass of all sites (474 kg $ha^{-1)}$ on backslopes and 596 kg ha^{-1} on swales. Weighted average phytomass was 2,013 metric tons for sites without topdressing compared to 68 metric tons for the native sites. Most of this phytomass is shrubs with a small portion (77 tons) being perennial forbs and grasses for the sites without topdressing.

The reclaimed spoil sites with topdressing had almost 10 times more phytomass than the six native sites. The majority (67%) was perennial forbs and grasses. Only a small portion was annual forbs and grasses. On a per hectare basis, swales had only slightly more shrub (67 kg) than backslopes (54 kg) and only slightly more perennial forbs and grasses (130 kg) than backslopes (125 kg).

CONCLUSIONS

When weigthted averages for the native sites are used, the values of cover, shrub density and phytomass are very small compared to reclaimed plots. This type fo comparison seems more representative than comparing reclaimed areas to the most productive native sites. The most productive native sites are typically small in area and realistically insignificant. As an example, the 2.1% of the lease identified as Razito is found in many small parcels that are too small to be considered land management units for grazing. They are actually managed as inclusions in the more extensive unproductive native sites (natrargrids and badlands). Reclaiming spoil without topdressing results in greater cover, shrub density and phytomass than areas reclaimed with topdressing. However, the reclaimed plots with topdressing are considered more desirable reclamation because of the greater proportion of perennial forbs and grasses and the increase in the plant diversity. Reclamation programs at Navajo mine are producing a more productive rangeland than what exists in the present native range within the lease.

Table 1. Total cover (%) for each vegetation category on native and reclaimed sites, summer, 1989.

	Annual forbs/grasses	Perennial forbs/grasses	Shrubs	Total perennial
	%			
Native sites[1]				
Badlands	0.03	0	0	0.03
Bacobi & Monierco	0.06	0.07	0.04	0.17
Farb & Persayo	0	0.03	0.04	0.07
Natrargids	0.18	0	0	0.18
Razito	0	0.01	0.10	0.11
Shiprock	0	0	0.01	0.01
Total	0.27	0.11	0.19	0.57
Reclaimed spoil sites without topdressing				
Backslopes[2]	0.92	0.23	5.12	5.36
Swales	0.05	0.05	0.40	0.50
Total	0.97	0.28	5.52	5.86
Reclaimed spoil with topdressing				
Backslopes[2]	0.09	0.99	0.44	1.52
Swales	0.01	0.07	0.10	0.18
Total	0.10	1.06	0.54	1.70

[1]These native sites comprise about 80% of the mining lease and are the most common on most productive sites.

[2]Calculations based on backslopes comprising 95% of reclaimed site and swales comprising 5%.

Table 2. Total number of shrubs on native and reclaimed sites, summer 1989.

	Atca[1]	Atco	Gusa	Other	Total
Native sites[2]					
Badlands	0	0	0	0	0
Bacobi & Monierco	26,903	1,155,708	0	53,784	1,236,395
Farb & Persayo	0	740,083	47,233	0	787,316
Natrargid	0	0	0	0	0
Razito	50,600	36,800	1,988,764	443,164	2,519,328
Shiprock	921	6,524	456,876	2,352	466,673
Total	78,424	1,939,115	2,492,873	499,300	5,009,712
Reclaimed spoil sites without topdressing					
Backslopes[3]	9,888,576	6,568	233,175	134,650	10,262,969
Swales	583,369	0	0	0	583,369
Total	10,471,945	6,568	233,175	134,650	10,846,338
Reclaimed spoil with topdressing					
Backslopes[3]	3,146,216	1,395,764	0	376,813	5,157,844
Swales	413,803	1,383	0	49,089	464,275
Total	3,560,19	1,397,147	0	425,902	5,622,119

[1]Atca = fourwing saltbush, Atco = shadescale, and Gusa = broom snakeweed (poisonous).

[2]These native sites comprise about 80% of the mining lease and are the most common or most productive sites.

[3]Calculations based on backslopes comprising 95% of reclaimed sites and swales comprising 5%.

Table 3. total phytomass (metric tons) for each vegetation category on native and reclaimed sites, summer 1989.

	Annual forbs/grasses	Perennial forbs/grasses	Shrubs	Total perennial
	metric tons			
Native sites[1]				
Badlands	0	0	0	0
Bacobi & Monierco	5	18	8	26
Farb & Persayo	0	10	9	19
Natrargids	16	0	0	0
Razito	0	1	19	20
Shiprock	0	1	2	3
Total	21	30	38	68
Reclaimed spoil sites without topdressing				
Backslopes[2]	335	72	1,484	1,891
Swales	19	5	98	122
Total	354	77	1,582	2,013
Reclaimed spoil with topdressing				
Backslopes[2]	7	410	177	594
Swales	1	22	12	35
Total	8	432	189	629

[1]These native sites comprise about 80% of the mining lease and are the most common on most productive sites.

[2]Calculations based on backslopes comprising 95% of reclaimed sites and swales comprising 5%.

PLANNING, REHABILITATION AND TREATMENT OF
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WARM SEASON GRASS ESTABLISHMENT ON SURFACE COAL MINE RECLAMATION IN THE SOUTHWEST

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ABSTRACT

WARM-SEASON GRASS ESTABLISHMENT ON SURFACE COAL MINE RECLAMATION IN THE SOUTHWEST

Warm-season grass establishment is being accomplished on surface coal mine reclamation in the Southwest with a variety of methods. These include primary establishment by drilling, broadcasting, and hydroseeding and secondary establishment by front-end loader and hand transplanting and direct topsoil replacement on the reclaimed landscape!

The established criteria for obtaining an acceptable stand of warm-season grasses involves selecting the best season for seeding, obtaining the highest quality seed, selecting the seeding method that works best under the given circumstances and mulching the area with high quality materials.

An overview of several approaches currently being utilized is provided, as well as an evaluation of seeding mixtures and mulching materials in use at these southwestern surface coal mines.

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INTRODUCTION

Warm season grass establishment has been a major concern of all southwestern surface coal mine reclamation programs. Methods of establishment for these species have concentrated on the proven techniques utilized for establishment of cool season grasses, shrubs and forbs.

Due to climatic differences in the southwest and the need for diversity in the post-mining landscape, the prefered season of seeding for these species occurs primarily during late spring through the end of August. This coincides with the late summer "rainy" season (July 15-August 31) when approximately 60-80% of the frost-free precipitation occurs.

This seeding season has proven successful for most species at the five mines examined in this document. However, the mixtures utilized at these mines also contain considerable percentages (Table 1) of cool season grasses, shrubs and forbs that may not have been seeded at their prefered times. Developing a seed mixture of all growth forms that are seeded in the summer, and still provide production, cover and diversity values capable of meeting bond release criteria has proven to be a complex problem in itself.

METHODS OF ESTABLISHMENT

The primary methods of warm season grass establishment in the southwest are by drilling, broadcasting and hydroseeding. Secondary establishment methods include front-end loader and hand transplanting; however, direct topsoil replacement may have the largest potential for use as a future primary method.

A. <u>DRILLING</u>

Drilling of grass, forb and most shrub species has been the principal method of establishment for many decades. Most warm season grasses are compatible with drills if seed quality is above average.

A wide variety of drills are available and in use on southwestern surface coal mines. The agricultural grass and grain drills in use have been modified for the wide variety of seeds being planted.

Most surface mines utilize some form of rangeland drill. These drills are usually more adjustable for the various seeds being planted, they can withstand the rugged reclaimed terrain and they generally can control the placement of seed on reclaimed areas more uniformly than standard agricultural drills.

Most warm-season grasses are relatively trashy and available primarily as florets. This quality requires the drills to have

agitation, picker wheels, or some other mechanism to prevent bridging of the seed and assure a uniform seed flow for calibration and seeding.

Drills must be capable of opening a furrow to a maximum of one inch to provide proper seed placement and a micro-topographic environment for limited initial water harvesting.

Seed covering may be accomplished with chains or drags depending upon the amount of soil coverage necessary.

In the Southwest, most seed mixtures are comprised of over 50 percent warm-season species. The trashy nature of these species may dictate that only the best quality be drilled and the others be applied by broadcasting or hydroseeding.

B. BROADCASTING

Broadcasting of warm-season grasses can have highly variable results. Simply doubling the seeding rate does not ensure success and, in fact, may not be necessary.

Broadcasting is the process of disseminating seed across the reclamation in a generally uniform pattern. Surface seedbed preparation may or may not have a marked effect on the success of warm-season species and ultimately other cultural practices may affect the success of broadcasting more than this methodology.

Several broadcasters are being used in the Southwest and include cyclone types, broadcast boxes on drills, and Vicon spreaders. Hand broadcasting of selected species is also being utilized to further supplement diversity.

C. HYDROSEEDING

This method involves mixing the seed and fertilizer (if necessary), with a wood fiber and water to form the hydroseeding mixture. A hay mulch is then blown onto the seeded area and this is anchored with a wood fiber and tackifier hydromulch. Typically, this method has been utilized for extremely steep slopes or hard to reach areas.

Very good success has been achieved in certain locations utilizing this method on more mesic slopes as a standard reclamation practice. Warm season grass establishment also appears to increase with this method. The summer seeding season combined with the mulching effect of hydroseeding may be the reason for this increase.

D. SECONDARY METHODS

Secondary methods of warm season grass establishment include front-end loader and hand transplanting of relatively small areas of mature individuals. While these methods don't establish large areas of vegetation, they can be important on difficult

areas. These mature plants also establish an adapted seed source on the reclamation where seedlings may take two to three years to provide their first viable seed.

These methods are usually more labor or equipment intensive than other primary establishment methods. For this reason, each reclaimed area should be evaluated to determine where and when to utilize them.

The final secondary method of warm-season grass establishment involves direct replacement of topsoil. While the logistics of this method must be evaluated on an area-by-area basis, careful pre-mine planning can minimize stockpiling of the topsoil resource.

The potential of this "live topsoil" resource is tremendous and should not be underestimated. In addition to the surface plants that are spread, regeneration from roots and stems will provide additional plants for at least two growing seasons. The real potential, however, lies in the amounts of dormant and pure live seed in the topsoil. The actual numbers of pure live seeds per acre are difficult to establish, but are likely to exceed current seeding rates by a large factor.

WARM SEASON GRASS ESTABLISHMENT CRITERIA

A. SEASON OF SEEDING

To facilitate warm-season grass establishment, all surface coal mines seed their reclaimed areas in the period from May to September. This is the period preceeding and during the season of most reliable precipitation.

Warm-season grasses are generally the most difficult species to establish in the diverse mixtures currently in use on coal mine reclamation in the Southwest. Since the soil temperatures must be adequate (above 70 F) and available moisture must be present, most companies attempt to complete their reclamation during the July and August rainy season.

This period generally provides 30 to 60 percent of the average annual precipitation, and occurs during the time when soil temperatures are highest in the region.

This timing alone will not guarantee that a warm-season grass stand will become established.

Warm-season grasses generally need 14 to 21 days of moist, warm soil temperatures to adequately germinate.

An additional ten days of ideal conditions provide enough growth to ensure that most seedlings will survive their first dormant period.

Due to the relatively high elevations and aridity of most southwestern coal mines, this three to four week period of optimal conditions may not occur every year. In certain locations, conditions may be ideal only once every three to four years. This results in a wide annual variation in success and may leave a sparse, warm-season grass stand that may be dominated by cool-season species.

From a reclamation success standpoint, these mixed results can be hard to interpret. Ultimate bond release criteria should be adjusted by data (precipitation, temperature and observational) collected during the first several years on <u>each</u> reclaimed area.

Several other noteworthy problems are encountered with the mid-summer seedings.

Many of the summer storms occur as short duration, high intensity precipitation events. This can translate into seeding delays and poor efficiency for the reclamation equipment. Of far greater importance are the erosional effects of these events. Reclamation results in disturbing the soils structure and leaving many particles detached. This process occurs at the time of greatest erosion potential. As discussed later, this emphasizes the need for

utilizing the best mulching materials to protect the soil until adequate revegetation occurs.

The second problem with summer seedings are the potentially deleterious effects on other growth forms in these reclamation mixtures. Approximately 30 percent of each mixture is composed of species that are better established by seeding in other seasons. This problem may be somewhat offset by utilizing adapted species within each growth form that have better longevity in the soil. The climatic differences between each seeding year will also favor certain species. Overall, most mines are aware of these inherent summer seeding problems but have few alternatives if they have mixtures composed primarily of warm-season grasses.

B. OBTAINING ADAPTED NATIVE SEED

Obtaining "adapted" native seed for use in reclamation programs has been a large concern for southwestern surface coal mines. A general definition for adapted seeds is that they are collected, propogated, or grown within about 250 miles of the mines geographic location.

When considering warm-season grass seed availability, the problem becomes much more complex. Reclamation specialists must consider if the species to be planted are commercially available; of the varieties that are adapted (if varieties have been released); and are of a quality that could be established at the mine.

The primary locations where warm-season grasses are grown commercially, are the western plains (Texas, Colorado, Nebraska and the Dakotas). Since there is a finite amount of each species grown, there is a very low chance of obtaining seed grown within 250 miles of the mine site.

Most warm season grasses have had varieties released that are "adapted" to certain areas, even though they are commercially grown elsewhere. Obtaining these varieties may be more important in terms of fine tuning a reclamation program than the overall species availability. In other words, planting 100 pounds of an adapted variety will yield more growing plants, than planting 400 pounds of an unadapted variety of the same species.

The seed quality is another major factor that ultimately can dictate seeding methods and rates. As previously stated, most warm-season species are very trashy in their floret form. Only small amounts of certain species are cleaned to the caryopsis form, yet despite the higher cost per bulk pound, this will generally be cheaper on a pure-live-seed basis.

C. SELECTING THE SEEDING METHODS

Many factors enter into selecting the best seeding method(s) for each reclamation situation. The reclaimed slope, aspect, intended post-mining land use and seed mixtures are several

of the factors that affect selection of these methods.

The prefered method of seeding warm-season grasses has been with the rangeland drill. The drill allows for accurate placement and coverage of the warm season species, assuming the seed is of acceptable quality.

When high quality seed can't be obtained, broadcasting or hydroseeding should be evaluated. Broadcasting is much less expensive and some warm-season species may actually establish better by this method. Sporobolus species have several million seeds per pound and may germinate better if soil coverage is minimized.

Hydroseeding should be evaluated on critical area plantings initially. It can then be utilized if successful warm season grass establishment can't be achieved by drilling and broadcasting.

D. MULCHING

Mulching materials and methods vary widely amoung southwestern surface coal mines. The objectives of mulching are to protect the soil from erosion, retard evaporation, provide a microclimate for seedling germination and to facilitate infiltration. Many other benefits can be realized from a well-designed mulching program (U.S.D.A. 1979).

Obtaining high quality mulching materials appears to be a problem for southwestern surface coal mines. Long stemmed native hay is not currently available in this region. Introduced hay crops have been imported from as far as Kansas to provide quality mulching materials. Long stemmed hay, bound into large round bales, has provided superior results on two surface coal mines in the southwest. This material, when properly applied and crimped, provides a very effective protection for the soil. In addition, it will be effective as a mulch for two to three years and does not cause an excessive carbon to nitrogen ratio.

This mulching process has proven more effective than small and large square bales of hay and cereal straw applied at similar rates. The brittleness and relatively short stems of the square bales severely limit the crimped effectiveness of these materials.

The main advantages that this mulching process provides for warm-season grass etablishment are that it significantly slows evaporation and therefore provides a longer establishment period and micro-climate for the warm-season seedlings. The additional infiltration of surface precipitation also provides more plant growth effective moisture while reducing overall runoff.

OVERVIEW OF SOUTHWESTERN SURFACE COAL MINE RECLAMATION PROGRAMS

BHP-UTAH -- NAVAJO MINE

The Navajo Mine is New Mexico's oldest and largest surface coal mine. It is situated at approximately 5500 feet of elevation in the South Central San Juan Basin of San Juan County, New Mexico.

The mine receives about 6.3 inches of precipitation annually and for this reason utilizes irrigation on all reclamation. First-year irrigation establishes the seeded species and second-year irrigation allows for stand development and seedling maturity.

Galleta is the best warm-season species to be established on the reclamation with Alkalai sacaton and Sand dropseed being established primarily on bottomlands. Warm-season species establish the first year because of irrigation. (Ramsey, 1989)

CARBON COAL COMPANY -- MENTMORE MINE

The Mentmore Mine was opened in 1978 and is currently in the final stages of reclamation. It is located in McKinley County on the southwestern edge of the San Juan Basin. The average elevation is approximately 6500 feet. The mine receives about 11 inches of precipitation annually.

Warm-season grass establishment is dependent upon seeding before August and receiving enough precipitation to allow for germination and growth before Fall. Drilling has proven to be the most reliable method of establishment for Galleta and Blue grama. Broadcasting has established Sand dropseed, Alkalai sacaton and Galleta. Galleta is best established by drilling at this mine and is the most successful warm-season species.

Warm-season grasses may germinate in the first year, but generally take two to three years to mature in this location. Blue grama and Alkalai sacaton are the predominant premining species due to excessive overgrazing, but do not dominate on the ungrazed reclamation.

PITTSBURG & MIDWAY COAL MINING CO.-- McKINLEY MINE

The McKinley Mine is situated at approximately 7000 feet on the southwestern flank of the San Juan Basin, McKinley County, New Mexico. This mine is topographically diverse and consists of Pinyon/Juniper rough breaks and grass bottomlands. The mine receives approximately 12 inches of precipitation annually.

The best warm-season species appears to be Alkalai sacaton with Galleta and Blue grama establishing in bottomland areas where additional protection is provided.

Reclamation personnel at this mine observe seedlings in the

early reclamation but feel that four to five years is necessary to establish a good stand of warm-season grasses. Experimentation with a variety of species and seeding methods is in progress at this mine. (Shorty, 1989)

PITTSBURG & MIDWAY COAL MINING CO. -- YORK CANYON MINE

The York Canyon Mine is located on the southwestern edge of the Raton Basin in Colfax County, New Mexico. This mine is on the eastern slopes of the Sangre de Cristo Mountains at an elevation of approximately 7600 feet and has an average annual precipitation of 13.8 inches.

Warm-season grasses establish very well in this environment by hydroseeding and drilling. Sideoats grama appears to be the best overall species with Little bluestem and Blue grama establishing better on sloping and flat areas, respectively. Galleta does well on arid, severe sites with the other warm-season species establishing on a more soil and site specific basis. Reclamation specialists at this mine observe good warm-season establishment in about two years. (Coats, 1989)

SANTA FE PACIFIC COAL COMPANY -- LEE RANCH MINE

The Lee Ranch Mine is located on the southeastern edge of the San Juan Basin, McKinley County, New Mexico. It receives approximately 12.0 inches of precipitation annually and is 6750 feet in elevation.

This mine conducted its first reclamation in 1985 and has been increasing the reclaimed acreage in each succeeding year. Galleta appears to be the best warm-season species at this location, with Blue grama and Alkalai sacaton establishing in more localized areas.

Although data is limited, reclamation specialists at this mine feel that three years of growth are needed to establish a good warm season grass stand. (Lewis, 1989)

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TABLE 1

KEY

GROWTH FORMS

W = Warm-Season Grass
C = Cool-Season Grass
S = Shrub (sub-shrub)
F = Forb (legume)

P. X G./100 X BULK SEEDS/POUND = PURE LIVE SEEDS/POUND (PLS/LB.)

PLS/LB. X PLS SEEDING RATE/43,560 = PLS/SQ.FT.

All seed mixtures were compared using average purity and germination values. Variations between seed lots can cause significant changes in the reported pure live seeds per square foot.

BHP-UTAH INTERNATIONAL, INC.--- NAVAJO MINE

SEEDING RATES: P.L.S.#/ACRE = 6.60
P.L.S./SQ. FT. = 71.28

NUMBER OF SPECIES: = 12
4 warm season grasses = 90.8%*
2 cool season grasses = 5.7%*
5 shrubs = 2.9%*
1 forb = 0.6%*

SEEDING METHODS:
A "Truax" grass seed drill is used to seed all species, except the small seeded species (Sporobolus spp.). These are placed in a broadcast box ahead of the drill.

MULCHING PRACTICES:
An annual grain straw is blown onto the reclaimed area at approximately two tons per acre. This is crimped into the surface along the contour.

SEASON OF SEEDING AND CULTURAL PRACTICES:
Depending upon operations, reclamation may take place from May to September. Irrigation is used to establish the seeded species. This generally consists of an initial application of one inch after seeding and about one half of an inch every other day for four to six weeks. After this, irrigation is applied at one inch per week through the growing season. The second year, water is added as needed but generally at one and one-half inches per month. Irrigation is removed after the second growing season.

Contour furrows are made prior to revegetation operations. These are part of the best technology currently available (B.T.C.A.) to this mine.

Fertilizer is applied to all reclaimed areas at approximately 200 pounds per acre. The fertilizer is 16-20-0 and is used for early plant establishment and to narrow the carbon to nitrogen ratio of the mulch.

* Percentage of mix is based upon pure live seeds per square foot (P.L.S./SQ. FT.).

BHP-UTAH INTERNATIONAL, INC. -- NAVAJO MINE

DRILL MIXTURE	GROWTH FORM	BULK SEEDS/LB.	PURITY[1]	GERM.[1]	PLS/LB.	P.L.S. SEEDING RATE(#)	PLS/FT^2
Alkalai sacaton	W	1,758,000	96	70	1,181,376	0.40	10.85
Fourwing saltbush	S	52,000	95	45	22,230	1.70	0.87
Galleta[2]	W	159,000	57	93	84,285	0.05	0.10
Giant dropseed	W	1,723,000	98	85	1,416,100	0.10	3.25
Indian ricegrass	C	141,000	98	88	121,598	1.00	2.79
Ephedra	S	19,000	98	90	16,758	0.80	0.31
Rubber rabbitbrush	S	400,000	13	80	41,600	0.10	0.10
Sand dropseed	W	5,298,000	94	88	4,382,505	0.50	50.30
Shadscale	S	64,900	99	56	35,980	0.70	0.58
Western wheatgrass	C	110,000	81	88	78,408	0.71	1.28
Winterfat	S	56,700	75	48	20,412	0.50	0.23
Scarlet globemallow	F	500,000	95	78	370,500	0.04	0.34
Totals						6.60	71.28[3]

1. Purity and germination data are average lot values provided by Granite Seed.
2. Florets
3. Navajo Mine reports seeding at 49.3 P.L.S./SQ.FT.

CARBON COAL COMPANY - MENTMORE MINE

SEEDING RATES:	P.L.S.#/ACRE	=	14.996
	P.L.S./SQ. FT.	=	64.225

NUMBER OF SPECIES: = 23

5	warm season grasses	=	57.53%*
4	cool season grasses	=	35.59%*
3	shrubs	=	3.33%*
11	forbs	=	3.55%*

SEEDING METHODS:

The drill mixture is applied with a "Laird" rangeland drill, then the broadcast mixture is applied with a "Vicon" broadcaster.

MULCHING PRACTICES:

Large round bales (1000 lbs.) of native and introduced grass hay are spread at approximately two tons per acre with a "Haybuster." The long-stemmed hay is then crimped into the soil on the contour.

SEASON OF SEEDING AND CULTURAL PRACTICES:

June 15 - September 15

No fertilizer is applied as the species requirements are low and the mulch does not create an unreasonably large carbon to nitrogen ratio.

A total of 1500 shrub transplants are added annually around rockpiles and topographic features to enhance diversity.

No irrigation or contour furrowing is applied to the area.

* Percentage of mix is based upon pure live seeds per square foot (P.L.S./SQ. FT.).

CARBON COAL COMPANY -- MENTMORE MINE

DRILL MIXTURE	GROWTH FORM	BULK SEEDS/LB.	PURITY[1]	GERM.[1]	PLS/LB.	P.L.S. SEEDING RATE(#)	PLS/FT^2
Western wheatgrass	C	110,000	81	88	78,408	3.00	5.40
Sideoats grama	W	191,000	48	71	65,092	1.50	2.24
Blue grama	W	825,000	60	90	445,500	1.00	10.23
Arizona fescue	C	550,000	95	74	386,650	1.00	8.88
Galleta[2]	W	470,000	77	92	332,948	1.00	7.64
Indian ricegrass	C	141,000	98	88	121,598	2.50	6.98
Needle & thread	C	115,000	75	81	69,862	1.00	1.60
Fourwing saltbush	S	52,000	95	45	22,230	1.25	0.64
Shadscale	S	64,900	99	56	35,980	1.25	1.03
BROADCAST MIXTURE							
Winterfat	S	56,700	75	48	20,412	1.000	0.470
Alkalai sacaton	W	1,758,000	96	70	1,181,376	0.250	6.780
Sand dropseed	W	5,298,000	94	88	4,382,505	0.100	10.060
Prairie aster	F	496,000	94	71	331,030	0.010	0.076
Butterfly flower	F	102,400	99	46	46,633	0.001	0.001
Blanket flower	F	132,000	98	75	97,020	0.018	0.040
Blue flax	F	293,000	99	94	272,665	0.025	0.156
White primrose	F	512,000	98	95	476,672	0.002	0.022
Palmer penstemon	F	610,000	98	98	585,844	0.025	0.336
Rocky Mt. penstemon	F	592,000	99	84	492,307	0.010	1.130
Purple prairie clover	F	293,000	99	93	269,765	0.025	0.155
Prairie coneflower	F	1,230,000	98	90	1,084,860	0.005	0.125
Scarlet globemallow	F	500,000	95	78	370,500	0.023	0.196
Showy goldeneye	F	1,055,000	99	80	835,560	0.002	0.038
Totals						14.996	64.225

1. Purity and germination data are average lot values provided by Granite Seed.
2. Caryopsis

P & M COAL MINING CO.-- McKINLEY MINE

SEEDING RATES: P.L.S.#/ACRE = 6.86
P.L.S./SQ. FT. = 48.42

NUMBER OF SPECIES: = 20
5 warm season grasses = 54.83%*
5 cool season grasses = 27.63%*
3 shrubs = 1.69%*
7 forbs = 15.84%*

SEEDING METHODS:
A rangeland drill is utilized to apply the cool season grasses and Fourwing saltbush. The other species are applied in two mixtures from a broadcast spreader mounted on the drill.

MULCHING PRACTICES:
A cereal straw is applied at approximately two tons per acre and currently is anchored with a land imprinter. A "Reinco" mulcher is used to shred and blow the mulch onto the reclamation. On steep slopes, contour furrowing is used with mulch being blown onto the area after seeding. No crimping or imprinting is done in this case.

SEASON OF SEEDING AND CULTURAL PRACTICES:
June 1 - August 15
Fertilization is applied where soil tests indicate a deficiency in the topsoils. The fertilizer is then disced into the soil.
Rough, unworkable topsoil may be chained to break clods and smooth the surface in preparation for other cultural practices.
Irrigation is not utilized at the McKinley Mine.

* Percentage of mix is based upon pure live seeds per square foot (P.L.S./SQ. FT.).

PITTSBURG & MIDWAY COAL MINING CO. -- McKINLEY MINE

SEED MIXTURE [4]	GROWTH FORM	BULK SEEDS/LB	PURITY [1]	GERM. [1]	PLS/LB.	P.L.S. SEEDING RATE(#)	PLS/FT^2
Western wheatgrass	C	110,000	81	88	78,408	0.89	1.60
Indian ricegrass	C	141,000	98	88	121,598	0.69	1.93
Arizona fescue	C	550,000	95	74	386,650	0.34	3.02
Mountain brome	C	90,000	99	95	84,645	0.34	0.66
Sandberg bluegrass	C	925,000	84	91	707,070	0.38	6.17
Alkalai sacaton	W	1,758,000	96	70	1,181,376	0.38	10.31
Spike muhly	W	1,600,000	81	88	1,140,480	0.38	9.95
Sideoats grama	W	191,000	48	71	65,092	0.51	0.76
Blue grama	W	825,000	60	90	445,500	0.45	4.60
Galleta [2]	W	159,000	57	93	84,285	0.48	0.93
Blue flax	F	293,000	99	94	272,665	0.07	0.44
Rocky Mtn. penstemon	F	592,000	99	84	492,307	0.21	2.37
Scarlet globemallow	F	500,000	95	78	370,500	0.21	1.79
White yarrow	F	2,770,000	98	95	2,631,500	0.03	1.81
Blanket flower	F	132,000	98	75	97,020	0.03	0.07
Blackeyed susan	F	1,710,000	98	85	1,424,430	0.03	0.98
Alfalfa	F	210,000	99	90	187,110	0.05	0.21
Fourwing saltbush	S	52,000	95	45	22,230	0.48	0.24
Winterfat	S	56,700	75	48	20,412	0.48	0.22
Shadscale	S	64,900	99	56	35,980	0.43	0.36
Totals						6.86	48.42 [3]

1. Purity and germination data are average lot values provided by Granite Seed.
2. Florets
3. McKinley Mine reports seeding at 24.0 P.L.S./SQ.FT.
4. Experimental mixtures used only in 1989.

P & M COAL MINING CO.-- YORK CANYON MINE

SEEDING RATES: P.L.S.#/ACRE = 7.68
P.L.S./SQ. FT. = 28.97

NUMBER OF SPECIES: = 19
7 warm season grasses = 69.03%*
3 cool season grasses = 22.43%*
4 shrubs = 1.98%*
5 forbs = 6.56%*

SEEDING METHODS:
All slope areas (90% of mine) are hydroseeded, flat areas are drilled; however, these are limited at the York Canyon Mine. Broadcasting is used on small areas that have limited access.

MULCHING PRACTICES:
Native hay is applied with a hay blower at a rate of two tons per acre. The hay is either crimped or hydrosprayed with a tackifier and wood fiber at a rate of 240 pounds per acre.

SEASON OF SEEDING AND CULTURAL PRACTICES:
April 15 - July 15

Fertilizer is incorporated into the soil prior to seeding. Phosphorus is added at 30 pounds per acre. Nitrogen is not currently utilized.

Irrigation and contour furrowing are not used at this mine.

Approximately 2,000 trees and shrubs are transplanted annually around topographic features across the reclaimed areas.

* Percentage of mix is based upon pure live seeds per square foot (P.L.S./SQ. FT.).

PITTSBURG & MIDWAY COAL MINING CO. -- YORK CANYON MINE

SEED MIXTURES	GROWTH FORM	BULK SEEDS/LB	PURITY[1]	GERM.[1]	PLS/LB.	P.L.S. SEEDING RATE(#)	PLS/FT[2]
Western wheatgrass	C	110,000	81	88	78,408	1.4	2.5
Little bluestem	W	260,000	55	85	121,550	1.2	3.4
Sideoats grama	W	191,000	48	71	65,092	2.7	4.0
Blue grama	W	825,000	60	90	445,500	0.6	6.1
Arizona fescue	C	550,000	95	74	386,650	0.4	3.5
Galleta [2]	W	159,000	57	93	84,285	0.7	1.3
Spike muhly	W	1,600,000	81	88	1,140,480	0.1	2.6
Indian ricegrass	C	141,000	98	88	121,598	0.2	0.5
Alkalai sacaton	W	1,758,000	96	70	1,181,376	0.06	1.6
Sand dropseed	W	5,298,000	94	88	4,382,505	0.01	1.0
FORBS							
Yarrow	F	4,123,635	99	95	3,878,278	0.01	0.90
Blue flax	F	293,000	99	94	272,665	0.10	0.60
Rocky Mtn. penstemon	F	592,000	99	84	492,307	0.01	0.10
Purple prairie clover	F	300,000	99	90	267,300	0.01	0.06
Prairie coneflower	F	1,230,000	98	86	1,036,644	0.01	0.24
SHRUBS							
Fringed sagebrush	S	4,536,000	10	85	385,560	0.05	0.44
Prairie sagebrush	S	4,500,000	10	82	369,000	0.01	0.08
Fourwing saltbush	S	52,000	95	45	22,230	0.10	0.05
Winterfat	S	56,700	75	48	20,412	0.01	0.004
Totals						7.68	28.974[3]

1. Purity and germination data are average lot values provided by Granite Seed.
2. Florets
3. York Canyon reports seeding at 60 P.L.S./SQ.FT.

S.F.P.C.C. -- LEE RANCH MINE

SEEDING RATES: P.L.S.#/ACRE = 9.51
P.L.S./SQ. FT. = 29.74

NUMBER OF SPECIES: = 9
- 5 warm season grasses = 66.6%*
- 2 cool season grasses = 31.9%*
- 2 shrubs = 1.5%*
- \- forbs = 0%*

SEEDING METHODS:

All seed is drilled with a "TYE" grass drill, it is then chained to cover the seed.

MULCHING PRACTICES:

Mulch consists of native grass hay, tame grass hay or straw and is applied at two tons per acre with a mulch blower. The mulch is anchored into the soil with a crimper.

SEASON OF SEEDING AND CULTURAL PRACTICES:
May 15 - July 15

Fertilizer is applied to all reclaimed areas at the rate of 60 pounds (N & P) per acre.

No irrigation or contour furrowing is used at this mine.

* Percentage of mix is based upon pure live seeds per square foot (P.L.S./SQ. FT.).

SANTA FE PACIFIC COAL CORPORATION -- LEE RANCH MINE

DRILL MIXTURE	GROWTH FORM	BULK SEEDS/LB	PURITY[1]	GERM.[1]	PLS/LB.	P.L.S. SEEDING RATE(#)	PLS/FT^2
Alkalai sacaton	W	1,758,000	96	70	1,181,376	0.20	5.42
Blue grama	W	825,000	60	90	445,500	0.80	8.18
Sideoats grama	W	191,000	48	71	65,092	1.80	2.69
Galleta[2]	W	159,000	57	93	84,285	1.30	2.52
Indian ricegrass	C	141,000	98	88	121,598	1.39	3.88
Sand dropseed	W	5,298,000	94	88	4,382,505	0.01	1.01
Western wheatgrass	C	110,000	81	88	78,408	3.11	5.60
Fourwing saltbush	S	52,000	95	45	22,230	0.31	0.16
Winterfat	S	56,700	75	48	20,412	0.59	0.28
Totals						9.51	29.74[3]

1. Purity and germination data are average lot values provided by Granite seed.
2. Florets
3. Lee Ranch reports seeding at 49 P.L.S./SQ.FT.

Planning, Rehabilitation and Treatment of Disturbed Lands
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NATIVE GRASSLAND BOND RELEASE CRITERIA USING TECHNICAL INFORMATION AND REFERENCE AREA DATA

Kathie J. Hirsch[1] and David J. Nilson[2]

ABSTRACT

Revegetation success standards using technical information in conjunction with reference area data for reclaimed native grasslands were developed for the North Dakota surface mining reclamation program. Soil Conservation Service (SCS) soil mapping unit and range site data are used to evaluate production, diversity and seasonal variety. Acreages of premine soil mapping units provide baseline information needed to accurately predict the vegetation potential, while reference areas provide a means to adjust data for climatic variation. Cover is evaluated using data from a representative reference area in conjunction with USDA Agricultural Research Service (ARS) data. Seasonality and species diversity can be evaluated using values derived from SCS range site technical guides or by direct comparisons to reference areas. In all evaluations, premine soil mapping units or range site acreages are used in the derivation of the standard. Use of these standards eliminates the need for extensive vegetation baseline studies and the need to establish reference areas for each range site.

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INTRODUCTION

North Dakota Surface Mining and Reclamation Rules require that success of revegetation be measured by using statistically valid techniques. Standards used must be approved by the Public Service Commission and the Office of Surface Mining [North Dakota Administrative Code (NDAC) 69-05.2-22-07(1)]. In March of 1989, North Dakota State Program Amendment X was approved by the Office of Surface Mining. This supplements the North Dakota Rules governing the reclamation of surface-mined land by the addition of standards for the evaluation and procedures for revegetation assessments.

Reference areas or approved technical standards must be used to verify that productivity, cover, diversity, seasonality and permanence of reclaimed native grasslands equal or exceed that of similar lands in the surrounding area under equivalent management. Direct comparisons with data collected from reference areas may be used as the criteria to evaluate these parameters, however, this requires representation of all range sites in the premine tract with an appropriate reference area. Since rangeland in North Dakota typically has a diverse landscape which is dissected into several mapping units or range sites (which often do not include large acreages), this type of assessment requires a large number of reference areas. Therefore, technical standards were developed for use on reclaimed native grasslands.

REFERENCE AREAS

The use of technical standards allows a reduction in the number of reference areas which must be established and maintained. However, reference areas are still necessary to adjust the data for climatic variation. This adjustment is required for all developed technical standards except the standards for species diversity and seasonality.

A reference area, defined by NDAC 69-05.2-01-02, is a land unit maintained under appropriate management for the purpose of measuring vegetation ground cover, productivity and plant species diversity. Reference areas must be representative of the geology, soil, slope and vegetation in the permit area. Range sites as defined by the SCS (1975) are used as the primary unit for reference area selection. In addition, the potential production of range sites is more accurately defined by production estimates of its component soil series; therefore, identification of the soil series is required.

Choice of range sites for reference areas is made by demonstrating that they adequately represent the premine area. Selection is based on: proper representation of range sites and soil series in the premine area, similarity of reference area production to production values provided by the SCS (1987), similarity of the range condition of the reference area to the premine area, and proximity to the permit area.

A minimum of one reference area is required for each bond release tract to adjust the standard for climatic variation. It is recommended that reference areas be established and maintained for all predominant range sites and that data from as many reference areas as possible be utilized. Reference areas used to correct for climatic variation must be representative of the soil of the reclaimed tract. If a reference area was not established on a soil mapping unit the same as that found on the premine tract, a reference area on a soil series representative of the reclaimed tract may be used to develop a climatic correction factor. Reference area data, used in conjunction with technical data for each range site or soil series, is weighted with the corresponding premine acreages to calculate the specific standard.

CHARACTERIZATION OF RECLAIMED AREAS

The use of these approved standards may require characterization of reclaimed areas to aid in the comparisons of values from unmined lands. The soil of the reclaimed tract may be

characterized by an evaluation of the premine soil survey and the expected mixing that will occur, or by a field analysis of respread soils. The predominant premine range site will generally contribute the most to the soil characteristics of the reclaimed tract. However, soils of reclaimed areas are uniformly respread and are more homogeneous and therefore there is no need to represent range sites which are extremely shallow or those which have restrictive layers. Reclaimed soils will most typically be similar to the predominant sandy, silty or clayey range sites.

EXAMPLE DATA

Data used for the examples in this paper are from a reclaimed native grassland tract and reference area at the Glenharold Mine, owned and operated by Basin Cooperative Services. This tract was selected because the vegetation exhibited excellent ground cover, high productivity, good diversity, and was seasonally balanced. This example was well-suited to identify where the approved standards are too lenient or too stringent.

The site was mined in 1979 and reclaimed to native grassland in 1981. Prior to mining, the area was dominated by silty and shallow range sites. Low areas were occupied by claypan and thin claypan range sites. Dominant plant species included, western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), needleandthread (*Stipa comata*) and threadleaf sedge (*Carex filifolia*). Premine soils consisted primarily of Amor (fine-loamy, mixed Typic Haploborolls) and Cabba (loamy, mixed (calcareous), frigid, shallow Typic Ustorthents) soils, with inclusions of Daglum (fine, montmorillonitic Typic Natriborolls) and Rhoades (fine, montmorillonitic Leptic Natriborolls) soils. The climate in this area is semi-arid, averaging 17 inches of precipitation a year. The majority of the precipitation occurs between April and July.

The soil of the reclaimed tract was characterized by an evaluation of the premine soil survey data and the mixing that occurred. The reclaimed site is typical of a silty range site, since all shallow, claypan, and thin claypan range sites were eliminated in the reclamation process. Soils of the reclaimed area are homogeneous. Soil samples taken at the time of bond release for meeting soil respread requirements verified an average topsoil thickness of 15½ inches and subsoil thickness of 33 inches throughout the tract.

Reference area data used in this paper are taken from silty and shallow range sites which were established in 1979. The soil series of the silty reference area is of the Temvik series, a fine-silty, mixed Typic Haploboroll. The soil series of the shallow reference area is of the Cabba series. Data from the silty reference area is used for climatic adjustments.

METHODS

To evaluate species composition, a 10-point frame was used to measure live basal cover (Cook and Bonham, 1977). In 1988 and 1989, 2000 points were randomly placed throughout the tract. Production data were collected at peak standing crop using a $0.25m^2$ frame. A total of 30 frames were sampled randomly throughout the tract. Sample size met all requirements of North Dakota State Program Amendment X, where the ratio of the standard error to the mean was <6%.

TECHNICAL STANDARDS

Production

A premine productivity standard for reclaimed native grasslands is derived utilizing SCS production values for a normal year (SCS 1987) weighted by premine soil series acreages (based on map unit composition), and corrected for annual climatic conditions using reference area data.

Production standards for the Glenharold Mine example area are calculated in Table 1. SCS production values of the soil series present in the premine tract are weighted by the premine acreages of each soil series, based on map unit composition. These values are multiplied by the annual climatic correction factor to adjust for variation. The weighted corrected production is divided by the total acres to derive the annual per acre standard. Where actual reference area data are available for a given soil series, those yields are weighted by the premine acreages rather than using SCS values. The climatic correction factor is calculated by dividing the actual production of the reference area by the SCS production estimates for its respective soil series. The silty reference area for the Glenharold Mine example area yields 2000 lb/ac in a normal year (SCS 1987). Table 1 illustrates how actual yields from the reference area, SCS technical data, and the climatic correction factor are used to determine the standard yield for each year. These values are compared to the actual yields from the reclaimed tract, and must meet the standard with 90% statistical confidence [NDAC 69-05.2-22-07(4)(a)(1)]. In 1988, the reclaimed area yielded 1409 lb/ac as compared to the standard of 1084 lb/ac. In 1989, the reclaimed area yielded 1454 lb/ac as compared to the standard of 1017 lb/ac. 1988 and 1989 were drought years and therefore the climatic correction factors lowered the standards.

Table 1. Reference area yield and SCS technical data yields corrected for annual climatic variation to calculate annual standards for comparison with reclaimed area data from the Glenharold Mine example area.

Premine Soils	Premine Acreage	RA[1] & SCS[2] Yields (lb/ac)		Corrected & Weighted Yields (lbs)[3]	
		1988	1989	1988	1989
Cabba	12.34	1151[1]	1046[1]	14,203.4	12,907.6
Amor	9.70	1224[1]	1169[1]	11,872.8	11,339.3
Daglum	7.31	1400[2]	1400[2]	6,242.7	6,038.1
Rhoades	0.73	700[2]	700[2]	311.7	301.5
Totals:	30.08			32,630.6	30,586.5
				Standards (lb/ac)[4]	
				1084	1017

[1] Reference area actual yield

[2] SCS Technical Data yield

[3] premine acres x RA or SCS yield x climatic correction factor
Where: 1988 climatic correction factor = 1224 lb/ac ÷ 2000 lb/ac = 0.61;
1989 climatic correction factor = 1169 lb/ac ÷ 2000 lb/ac = 0.59;
no climatic adjustment necessary when actual RA yield is available

[4] Corrected Weighted Yield in lbs ÷ 30.08 ac

Ground Cover

The cover standard for a reclaimed native grassland tract is derived by utilizing cover data from representative reference area(s) in conjunction with a fixed standard based on ARS data (Hofmann et. al. 1983, and Ries and Hofmann 1984). A minimum of one reference area is required for each bond release tract to ensure cover is similar to that occurring in natural vegetation of the area. The ARS standard is based on cover required to adequately protect grassland areas from erosion (i.e., 73% basal cover or 83% first-hit cover). Cover for premine range sites not represented by reference areas is represented by ARS data. Cover values are weighted by representative premine range site acreages.

A silty range site is most representative of the reclaimed tract in the Glenharold Mine example (Table 2). Other range sites of the premine tract are represented by 73% basal cover.

Table 2. Example calculation of cover standard based on 1988 silty reference area data and premine range site acreages for the Glenharold Mine example area.

Premine Range Sites	Premine Acreage	Basal Cover	Weighted Cover
Shallow	12.34	73%[1]	900.82
Silty	9.70	99%[2]	960.30
Claypan	7.31	73%[1]	533.63
Thin claypan	0.73	73%[1]	53.29
TOTAL:	30.08		2448.04

1988 Standard = 2448.04 ÷ 30.08 acres = 81.4% basal ground cover

[1]ARS data (Hofmann et. al. 1983, and Ries and Hofmann 1984)
[2]Glenharold Mine data for 1988, based on basal cover

The weighted cover divided by the premine acreage provides a cover standard of 81.4% basal ground cover for 1988 data. In 1988, ground cover of the Glenharold Mine reclaimed example area was measured and found to be 96%. The calculated standard for 1989 was 82%, compared to reclaimed area cover of 98%. These values must meet the standard with 90% statistical confidence [NDAC 69-05.2-22-07(4)(a)(1)].

Diversity

Two standards were developed to evaluate diversity of reclaimed grasslands. One relies on derivations of technical data only, while the other uses reference area data. Species diversity standards were developed to ensure that a reasonable number of species were present in the stand and in sufficient amounts to develop into an ecologically stable, self perpetuating grassland.

Diversity Standard using Technical Data

A standard diversity value was developed for each range site using SCS range site descriptions (SCS 1975). Allotment values were assigned based on percent composition by weight of the dominant species expected to occur on a range site in excellent condition. This procedure includes counting all predominant species and groups identified for each range site. Individual species which contributed 5% or more composition was counted as one; two or three species within a group, contributing 10%, were counted as one; and two or three species within a group which contributed 15% or more, were counted as two.

The premine standard for the Glenharold Mine example area is derived in Table 3. To assess the diversity, the standard is derived by weighting the diversity allotment value for each range site present in the premine tract by the acreage which that range site occupied in the tract prior to mining. These values are summed to obtain the target diversity allotment for the entire tract. The total diversity allotment is divided by the total acreage of the tract to obtain a per acre value.

The diversity value of the reclaimed tract is assessed by relative species composition by weight. The methodology of counting species is similar to that used in the derivation of SCS allotment values, i.e., species which contribute more than 5% composition by weight are counted as one; two or three species together contributing 10%, are counted as one; and two or three

species which contributed 15%, are counted as two. Data from the Glenharold Mine example area, Table 4, indicate that four species were counted towards species diversity in 1988 and 1989. These values do not meet the standard of 7 species.

Table 3. Calculation of the diversity standard using technical information derived from SCS range site descriptions for range sites and acreages found on the Glenharold Mine example area.

Premine Range Sites	Premine Acreage	Diversity Allotment[1]	Weighted Allotment
Shallow	12.34	8	98.72
Silty	9.70	5	48.50
Claypan	7.31	7	51.17
Thin claypan	0.73	5	3.65
TOTAL:	30.08		202.04

Standard = 202.04 ÷ 30.08 acres = 7 species

[1]derived from SCS 1975

Table 4. Relative species composition based on production data from the Glenharold Mine example area used to derive the number of species contributing to species diversity.

	1988		1989	
Species	% Rel Comp[1]	Value[2]	% Rel Comp[1]	Value[2]
Western wheatgrass	25.95	1	54.82	1
Pubescent & Intermediate wheatgrass	4.17	0	12.41	1
Green needlegrass	16.83	1	10.79	1
Bluegrass	5.54	0[3]	0.08	0
Smooth bromegrass	0.88	0	4.80	0
Big bluestem	0.32	0	0.00	0
Little bluestem	2.00	0	0.09	0
Blue grama	20.32	1	5.27	1
Side-oats grama	13.51	1	3.92	0
Switch grass	0.40	0	0.00	0
Other	0.47	0	0.09	0
native forbs	0.63	0	0.77	0
introduced forbs	8.98	0[3]	7.03	0[3]
TOTAL	100.00	4	100.00	4

[1]percent relative species composition by weight
[2]species diversity allotment count based on percent composition
[3]do not meet criteria to count towards species diversity (i.e., introduced)

Diversity Standard using Reference Area Data

The diversity of species found on the reclaimed tract may be compared directly to reference areas that are representative of the reclaimed area. A standard value for diversity is derived based

on acreages occupied by each range site in the reclaimed area. Measurements taken to compare the reference area and reclaimed area may be based on relative species composition as determined by cover or production data. In either case, measurements and number of samples must be the same for both reclaimed and reference areas. Species counted for the standard for reference areas and reclaimed area must have a minimum percentage of relative species composition. If cover data are used, species counted must comprise 3% or more basal or first-hit cover; or if production data are used, species counted must comprise 5% or more of the relative composition.

In the calculation of the diversity standard, the number of species derived from the relative species composition for each reference area is weighted by the corresponding acreage found in the reclaimed native grassland tract. The weighted value is then divided by the total acreage of the tract to obtain a per acre value.

In the Glenharold Mine example area, the silty range site was the only range site characterized on the reclaimed tract. Data from the silty reference area indicates 5 species in 1988 and 4 species in 1989 contributed 3% or more relative basal cover (Table 5). The reclaimed area possessed 4 species in 1988 and 5 species in 1989. The diversity standard was achieved in 1989, but not in 1988.

Table 5. Relative basal cover data from the silty range site and Glenharold Mine example area used to derive the number of species contributing to species diversity.

Species	Reference Area % Rel. Spp Comp.[1]		Reclaimed Area % Rel. Spp Comp.[1]	
	1988	1989	1988	1989
Western wheatgrass	**8.65**	2.22	**37.33**	**35.35**
Pubescent wheatgrass	0.00	0.00	**8.22**	**7.58**
Intermediate wheatgrass	0.00	0.00	0.34	0.00
Crested wheatgrass[2]	0.00	0.00	1.03	0.00
Prairie june grass	0.54	0.00	0.00	0.00
Needleandthread	**27.57**	**45.93**	0.00	0.00
Green needlegrass	2.16	1.48	2.40	**7.58**
Bluegrass	0.00	2.22	0.00	0.00
Sedge	**15.68**	**20.00**	0.00	0.00
Smooth bromegrass[2]	0.00	0.00	0.34	2.02
Blue grama	**39.46**	**21.48**	**36.99**	**36.87**
Side-oats grama	0.00	0.00	**11.30**	**5.56**
Switch grass	0.07	0.00	0.68	0.00
Native forbs	2.70	**5.93**	0.00	0.00
Introduced forbs[2]	0.00	0.00	1.37	2.53
Shrubs	**3.24**	0.74	0.00	0.00
Number of species >3% cover[3]:	5	4	4	5

[1]percent relative species composition, live basal cover
[2]do not meet criteria to count towards species diversity (i.e., introduced)
[3]species diversity allotment count based on $\geq$3% live basal cover

When the diversity standard is applied using production data (i.e., those species which comprise 5% or more relative composition by weight), the standard derived from the reference area was 5 species in both 1988 and 1989, whereas the reclaimed area yielded 4 species in both years.

Seasonality

To evaluate seasonality of reclaimed native grassland, one of two standards may be used. Both are based on the percent relative composition of warm season grasses (as determined by total species composition). The percentage of warm season grasses is used as the minimum standard since cool season grasses are very competitive and generally dominate a seeded stand in the Northern Great Plains.

Seasonality Standard Using Technical Information

A seasonality standard was developed for each range site using descriptions and data for individual range sites (SCS 1975). The values for seasonality were derived from the percent relative composition by weight of warm season grasses which occur on a range site in excellent condition. For example, blue grama contributes 15% relative composition on a silty range site in excellent condition. Blue grama is the only warm season species listed for a silty range site. The total contribution of warm season species is summed to obtain the minimum percentage of warm season species required.

The total percent composition of warm season grasses for each range site is weighted by the acreage which the range site occupied in the tract prior to mining. The weighted percentages for all range sites in the reclaimed tract are summed and divided by the total acreage of the tract to obtain the seasonality requirement. Table 6 illustrates the calculation for the Glenharold Mine example area. On reclaimed tracts, seasonality is assessed by obtaining the relative composition of warm season grasses by weight.

Table 6. Calculation of the seasonality standard using technical information derived from SCS range site descriptions for acreages used for the Glenharold Mine example area.

Premine Range Sites	Premine Acreage	% warm season[1]	Weighted Value
Shallow	12.34	50	617.00
Silty	9.70	15	145.50
Claypan	7.31	25	182.75
Thin claypan	0.73	30	21.90
TOTAL:	30.08		967.15

Standard = 967.15 ÷ 30.08 acres = 32% warm season species by weight

[1]derived from SCS 1975

The standard of 32% warm season grasses by weight is not corrected for annual variations. Percent relative composition by weight of warm season species on the Glenharold Mine example was 37% in 1988, and 9% in 1989.

Seasonality Standard Using Reference Area Data

The percentage of warm season grass species found on the reclaimed tract may be compared directly to reference areas that are representative of the reclaimed area. Reference areas must be established for all range sites that are expected to develop on the reclaimed area. Measurements

taken to compare the reference area and reclaimed area may be based on either cover data or composition by weight. In either case, the measurements and number of samples must be the same for both the reference and reclaimed areas.

In the calculation of the seasonality standard, the percentage of warm season species derived from the relative species composition for each reference area is weighted by the corresponding acreage found in the reclaimed native grassland tract. The weighted value is then divided by the total acreage of the tract to obtain a per acre value. The percentage of warm season grasses measured on the reclaimed area must be determined using the same sampling methodology used on the reference areas to enable direct comparisons.

On reclaimed tracts, seasonality is assessed by obtaining the relative composition of warm season grasses. The relative composition of warm season grasses must at least equal that of the derived standard. In the Glenharold Mine example area, the silty range site is the only range site characterized on the reclaimed tract. Data from the silty reference area, using basal cover data indicates standards of 42% warm season species in 1988, and 23% in 1989 (Table 7). Based on basal cover measurements, the reclaimed area had 50% warm season species in 1988, and 44% in 1989.

Table 7. Relative basal cover data from the silty range site and Glenharold Mine example area used to derive the percentage of warm season species contributing to the seasonality standard.

Species	Reference Area % Rel. Spp Comp.[1]		Reclaimed Area % Rel. Spp Comp.[1]	
	1988	1989	1988	1989
Western wheatgrass	9.20	2.38	37.85	36.27
Pubescent wheatgrass	0.00	0.00	8.33	7.77
Intermediate wheatgrass	0.00	0.00	0.35	0.00
Crested wheatgrass	0.00	0.00	1.04	2.59
Prairie june grass	0.57	0.00	0.00	0.00
Needleandthread	29.31	49.21	0.00	0.00
Green needlegrass	2.30	1.59	2.43	7.77
Bluegrass	0.00	2.38	0.00	0.00
Sedges	16.67	21.43	0.00	0.00
Smooth bromegrass	0.00	0.00	0.35	2.07
Blue grama[2]	**41.95**	**23.02**	**37.50**	**37.82**
Side-oats grama[2]	**0.00**	**0.00**	**11.46**	**5.70**
Switch grass[2]	**0.07**	**0.00**	**0.69**	**0.00**
% warm season species:	42.02	23.02	49.65	43.52

[1]percent basal cover, relative grass species composition
[2]warm season species

Permanence

Ground cover, productivity, diversity and seasonality criteria are used to assess the permanence of established vegetation. The revegetation responsibility period of ten years provides sufficient time to substantiate vegetation establishment and regeneration. Therefore permanence is an indirect measure of these other standards since they ensure a diverse perennial grassland stand which, inherently, ensures permanence.

RESULTS AND DISCUSSION

The standards were designed to ensure that the postmining vegetation is of equal or superior utility for the landuse when compared to the utility of vegetation existing prior to mining [NDAC 69-05.2-22-01]. With the exception of the diversity standard and the duration of the 10-year liability period, the Glenharold Mine reclamation site has satisfied all revegetation requirements. The use of premine acreages of soil series or range sites has proven to be a good estimate of the capability of each area. In most cases, the standards have more than adequately met the requirements of NDAC 69-05.2-22-01. However, close scrutiny of these standards has led to some concerns.

Modification of the production standards may be necessary to specify limits in the yield range allowed. The use of a one-tailed t-test with a 90% confidence limit allows the operator some deviation from the set standard. However, since the standard deviation associated with vegetation data is often high, applying the t-test allows much variation in yields. Although some deviation should be allowed, the inherent nature of vegetation data results in wider ranges than is practical for the land use. From data submitted for bond release requirements, it has become apparent that the standards are more difficult to obtain in years when precipitation is above average. It will be necessary to monitor this trend to determine if there is a problem with the standard, or if it is operational in terms of determining the production limits of reclaimed tracts.

The cover standard is functional in that it ensures a vegetative cover capable of stabilizing the soil surface. Since the standard is in part derived from ARS data (Hofmann et. al. 1983 and Ries and Hofmann 1984) and reference area data, it is highly variable. It is easily skewed, being dependent on the amount of acreage represented by reference areas, and that which is represented by ARS data. Use of reference area data is less attractive to operators since the cover standard becomes more stringent with their use.

Diversity standards were established with two goals. First, to ensure that a reasonable number of species were present in the reclaimed tract, and secondly to ensure that each species counted was abundant enough to ensure perenniality and community contribution. The standard which uses technical information may be too stringent, in that there is no flexibility for annual variation. Both standards are also subject to variation based on methods used to analyze vegetation. The use of data derived from species composition by weight may not as accurately reflect species contribution, since there is more variation in weight between species than in cover. For example, blue grama may occur in enough quantity to be self-perpetuating, and even flourish in grazed conditions, but due to its light weight may not count towards species diversity. Whereas, cover measurements, especially basal, will more accurately reflect its contribution. Based on data from the Glenharold Mine example area, both diversity standards appear to be somewhat stringent as compared to actual field diversity.

Measurement of the seasonality poses similar concerns. The standard which relies on technical data does not account for annual variation. With seasonality, this is an important controlling factor since temperatures and the timeliness of rainfall within a growing season have a great effect on the species composition. For example, Table 7 illustrates changes in species composition between 1988 and 1989. These changes can be more pronounced if production data are used. Both the reclaimed area and the reference area show decreases in the warm season component in 1989.

North Dakota Program Amendment X provides mining companies the flexability of using technical standards, reference areas, or a combination of both to determine rangeland reclamation success. Changes in the performance standards will be necessary as problems arise in the application of these standards and methodologies. Additionally, this document recognizes the operational and resource differences between mine operations. Acquisition and maintenance of reference areas can be a problem especially if it requires obtaining representative sites outside of a permitted area. Prior to this effort, one must consider whether or not securing reference areas for each range site would improve the accuracy of the comparisons. As an alternative, available SCS technical data can provide the necessary data to minimize labor costs and other problems associated with reference areas.

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Planning, Rehabilitation and Treatment of Disturbed Lands
Billings Symposium, 1990

ECO-RESTORATION MODEL FOR SURFACE MINED LANDS

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ABSTRACT

Surface mining for minerals creates vast stretches of derelict lands which are, technically speaking, areas of "no value" from economic, social and aesthetic points of view. Problems due to surface mining are manifold, e.g. deforestation, soil erosion, pollution of water, air, noise, etc. and depletion of nutrients.

In this paper we discuss the eco-restoration model developed for restoring surface mined lands in one of the most fragile ecological regions of the country. Use of ecologically suitable native species of grasses, shrubs and trees for restoration lead to stabilization of the overburden dumps in a short span of five to six years. At the same time, the vegetation provides for the ecological succession of flora and fauna, water pollution control, and is capable of giving socioeconomic returns in terms of fuel, fodder, fiber etc.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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A GEOSTATISTICAL AND SAMPLING ANALYSIS OF REGRADED SPOIL MATERIALS

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ABSTRACT

Characterization of the pH and acid-base account levels in regraded spoil materials from mining operations is a difficult task due to mixing and the directional nature of product extraction. Geostatistical analysis of regraded spoil materials is currently being studied as the eventual methodology for determining sample grid size and sub-sample number for minesoil monitoring programs in the State of Texas. It is anticipated that geostatistics will soon be utilized for similar reasons at mine sites in other regions. In view of this, it is necessary to develop a position on geostatistics as a method for determining sample intensity necessary to statistically characterize Acid Forming Material (AFM) conditions existing in post-mined soils.

A group of six Texas lignite coal mines has been analyzed using geostatistical methods. Acid-base account and pH values were mapped at four levels in each site. Determinations as to the confidence of the sampling programs were performed for all sites. Recommendations and strategies were developed for future sampling programs. Additional techniques to minimize sub-sample spacing were also developed.

INTRODUCTION

Coal mine operators are currently required by applicable laws and regulations to reclaim mined sites by applying predetermined amounts of top-soil, and maintaining a root zone free of acid and toxic forming materials. In some areas, there are allowances that allow substitution for topsoil if the material used meets specific quality and productivity standards. Regraded spoil monitoring programs are being required in many states by the regulatory

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authorities to assure that coal mining operations maintain compliance with the regulatory requirements. Because of the seemingly random nature of regraded spoil materials, sampling programs that adequately characterize the sampled area are an exception. Both operators and regulatory agencies are investigating methodologies that will effectively identify problem areas. This study has been undertaken in order to evaluate geostatistical methods as a means of effectively characterizing regraded spoil materials.

The geostatistical techniques of variograms and kriging have been tested on data for six selected sites. Each site is representative of Texas mining conditions. Determinations with respect to two variables, pH and acid base account, have been made in each site. A series of maps has been produced to illustrate the results of a geostatistical analysis and to display pH, acid base, and error values. The percentages of spoil areas that are below acceptable threshold values for each site were then calculated.

GEOSTATISTICAL CONSIDERATIONS

The theory of regionalized variables, commonly known as geostatistics, is now being applied throughout the community of engineering and earth sciences (Myers and Bryan, 1983; Mernitz et al, 1986, Sullivan et al, 1988). Measurements taken at different spatial locations, called spatial data, are analyzed for statistical properties that allow powerful estimating techniques to be employed. Variograms and kriging provide the foundation of geostatistics and allow the maximum amount of information to be gained from each sample data point.

Geostatistics is intimately associated with map making, one of the major goals of this study. Kriging provides the estimation or gridding algorithm that allows unsampled locations to be estimated from surrounding data. The resultant map is then used to make decisions for remedial action. Thus, the quality of the map is of considerable importance in the decision making process.

The quality of a map varies for two reasons. First, some maps are better than others because of superior collaboration between the map maker and the mapping algorithm being used. Second, the quality of any map is a final expression of the resolution of the underlying information. Geostatistics allows one to glean the maximum amount of information from each sample.

All contouring methods, including kriging, take known data values and extend them into areas which have not been sampled, producing a new estimated value. Since these estimated locations have not actually been sampled, an error will be made in the estimation. The variogram can be thought of as a graph of the expected error made in projecting these known values over a distance and direction. The greater the error, the greater the resulting map.

Figure 1 displays a variogram. The horizontal axis is a scale representing the separation distance between a known and an unknown point in a particular direction. The vertical axis is a scale of the expected error in using the measured value of the known point to infer the known point. The range indicates how far correlation exists, or how far information may be shared. The sharing of information produces better estimates and better maps.

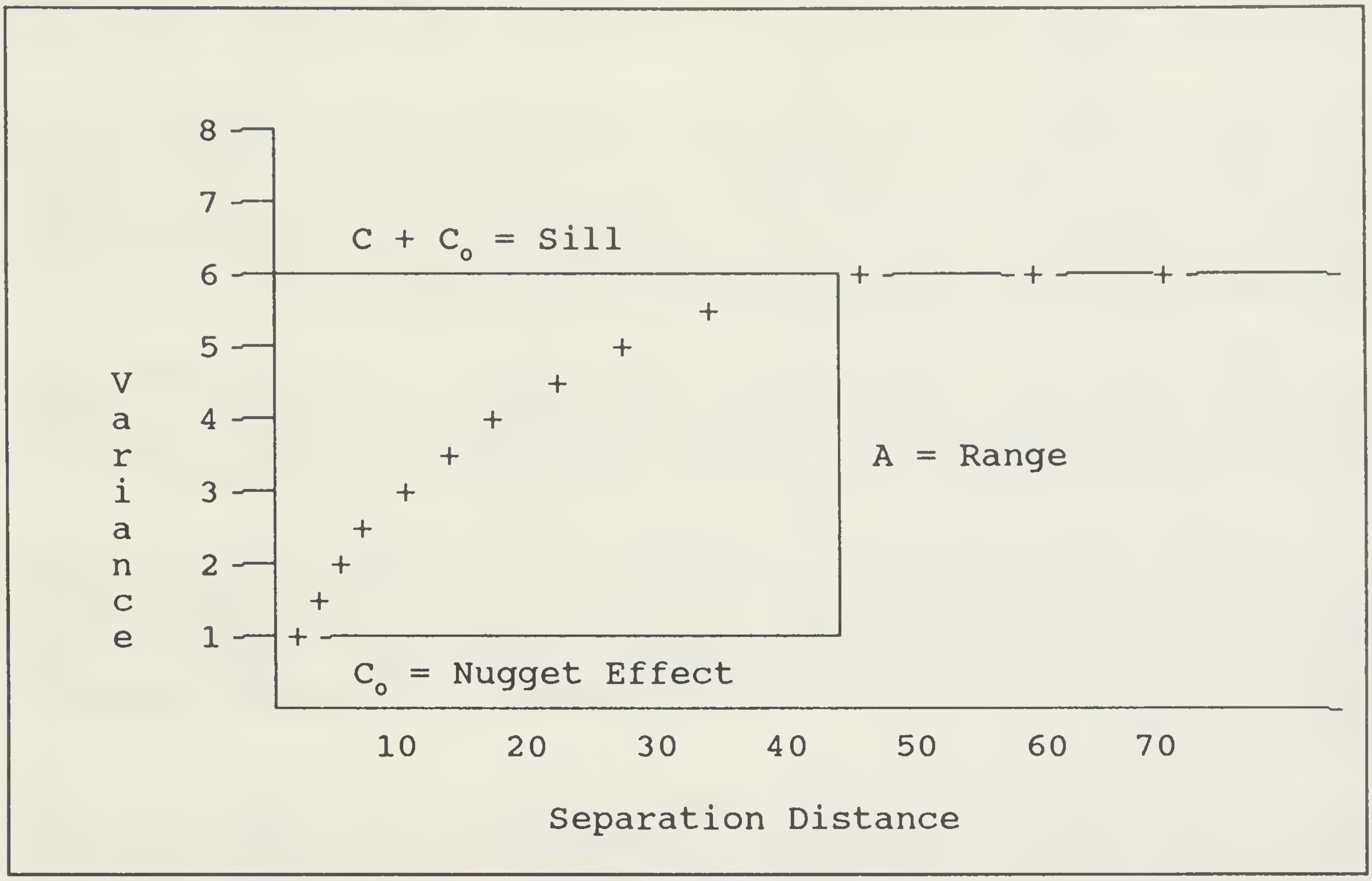

Figure 1: THEORETICAL VARIOGRAM

Using the variogram, kriging fits a surface over the existing sample data at regular grid locations. These estimates carry with them the error of estimation, i.e. the precision with which one knows the estimate. These data and error grids are suitable for many types of graphic display. Most commonly this occurs in the form of a contour or isopleth map.

STATISTICAL ANALYSIS

The analytical portion of this study was divided into three phases. Phase 1 concentrated on determining the standard statistical population parameters for the data. Phase 2 analyzed the variography. In Phase 3 the gridding, contouring, and area calculations were performed.

Each of the six sites had been sampled at 100 locations to a depth of four feet. These values represent a 100' x 100' square grid. Each of these locations was separated into four sample intervals of one foot each. This resulted in four data sets of 100 samples each for each of the six areas. Thus a total of twenty four data sets with two variables each was produced.

Both of the variables in each of the 24 data sets were analyzed for the associated distribution parameters. These parameters included the mean value, variance, standard deviation, maximum, median, data range, and coefficient of variation.

Result summaries for the statistical analyses of pH and acid base account data are shown in Tables 1 and 2 respectively. These tables show results for means, standard deviations, minimums, and maximums. All results were calculated on sample sizes of 100. Declustering of the data set was unnecessary due to the perfectly regular grid.

Almost 80% of the areas had mean pH values below 7.0, the neutral state. None, however, had mean values below the threshold of 5.0. None of the mean acid base account values were below the threshold value of 0.0, although several values approached it.

One thing to note is that background values for pH and acid base account in undisturbed soils typically average below 5.0 and below 0.0 respectively. The regraded disturbed soils are on the average considerably less acidic.

Area	Level	Mean	S.D.	Min.	Max.
I	1	6.79	.557	3.80	7.60
	2	7.06	.575	4.40	7.90
	3	7.11	.712	3.10	8.00
	4	7.03	.965	3.10	7.90
II	1	6.62	.977	2.70	7.90
	2	6.37	.990	3.80	7.80
	3	6.50	.920	3.90	7.90
	4	6.46	1.018	3.90	7.60
III	1	6.70	.846	4.10	7.90
	2	6.26	1.249	3.10	7.80
	3	6.29	1.230	2.90	7.80
	4	6.36	1.149	2.80	7.90
IV	1	6.51	.668	5.00	7.60
	2	6.66	.683	4.90	7.80
	3	6.65	.724	4.70	7.80
	4	6.60	.814	4.20	7.80
V	1	6.94	.376	5.60	7.70
	2	7.32	.728	5.20	8.40
	3	7.39	.723	4.60	9.30
	4	7.28	.777	4.20	8.80
VI	1	5.69	.916	4.00	7.60
	2	5.68	1.018	4.20	7.60
	3	5.99	1.160	4.20	8.10
	4	6.18	1.232	4.30	8.20

TABLE I: SUMMARY STATISTICS FOR pH VALUES

Area	Level	Mean	S.D.	Min.	Max.
I	1	6.81	2.62	-1.24	15.70
	2	6.49	2.49	1.31	19.20
	3	7.04	3.72	-6.04	25.10
	4	7.04	4.59	-8.08	25.60
II	1	8.10	6.43	-12.90	36.10
	2	6.77	6.03	-19.80	27.60
	3	7.42	5.65	-3.27	24.70
	4	6.81	5.72	-5.94	28.40
III	1	5.99	4.22	-1.18	18.20
	2	6.13	6.74	-8.11	32.10
	3	6.42	7.22	-7.01	32.10
	4	6.47	8.38	-11.30	28.90
IV	1	5.17	2.29	1.19	14.60
	2	5.08	2.36	0.94	13.00
	3	5.50	2.91	-1.48	20.10
	4	5.59	3.10	-2.82	16.10
V	1	7.55	2.52	1.69	17.50
	2	8.06	3.38	2.06	32.00
	3	7.88	2.75	0.40	17.10
	4	7.96	2.86	-3.28	14.00
VI	1	1.84	2.26	-2.60	7.87
	2	1.94	3.08	-5.53	10.20
	3	2.56	3.15	-3.91	8.74
	4	3.20	3.77	-3.87	17.40

TABLE 2: SUMMARY STATISTICS FOR ACID BASE ACCOUNT VALUES

Mean pH values showed a tendency in many areas to increase with depth. Notable exceptions were Area II and Area III. Variances showed an even stronger tendency to increase with depth as well. Area III was the most notable dissenter. Also, Areas II and III show notably higher pH values in the 0-1 foot level than in the levels beneath.

Acid base account parameters also were similar in nature. Area VI was the one exception with relatively low mean values. Variances (and data ranges) were higher than for pH values as expected due to the greater latitude in allowable variable As with pH, mean values and variances tended to increase with depth. Area III was generally the exception.

VARIOGRAPHY

Experimental variograms were calculated for both pH and acid base account. During the analysis, two types of variograms were run. These were absolute variograms and general relative variograms. All twenty four data sets were analyzed for both variables.

The variography was examined in five different directions: north-south, east-west, northeast-southeast, southeast-northwest, and the omnidirectional average variogram. Lag distances were set equal to one grid unit. The directional variograms were allowed windows of 45 degrees.

The results of the experimental variograms were mixed. Most of the graphs show spatial continuity structures. Still, the ratio of the nugget component in relation to the overall sill is quite high in many cases. This indicates significant intrinsic randomness in the system. This was not surprising considering the nature and history of the soil material. This randomness was reflected in the kriging variances. However, only absolute and general relative variograms were run, no logarithmic or indicator transformed variograms were attempted.

A second set of variograms was then produced. This time, data cutoff values were imposed. These cutoffs excluded the distributional outliers, allowing the true underlying spatial structure to be observed. Typically two to three percent of the distribution was excluded, and a maximum of five percent was allowed.

Two more additonal sets of experimental variograms were produced. While retaining the outlier cutoffs, the variogram orientations were rotated 15° east of north instead of due north. All other directions underwent this same rotation. Because the sampling grid was oriented north and south, it does not necessarily follow that the spatial structure will be oriented this way. The

directional nature of the mining would be expected to contribute more than the orientation of the sampling grid. This rotation was done as a precautionary check on the spatial structure. The fourth and final analysis oriented the variograms 30° from north. By doing these rotations combined with the original orientation, the data was analyzed in 15° increments around the entire map.

The variograms were modeled via an interactive variogram modeling program. An example is shown in Figure 2. The parameters of the fitted theoretical models for pH and acid base account are listed in Table 3 and 4 respectively. Note that a range of 1.0 refers to 1.0 grid unit, and actual distance of 100 feet. Some zones proved to have no spatial correlation, but these were the exception. Roughly two-thirds of the models showed anisotropy. Most of the long axes of continuity were due east, the direction of mining, as expected.

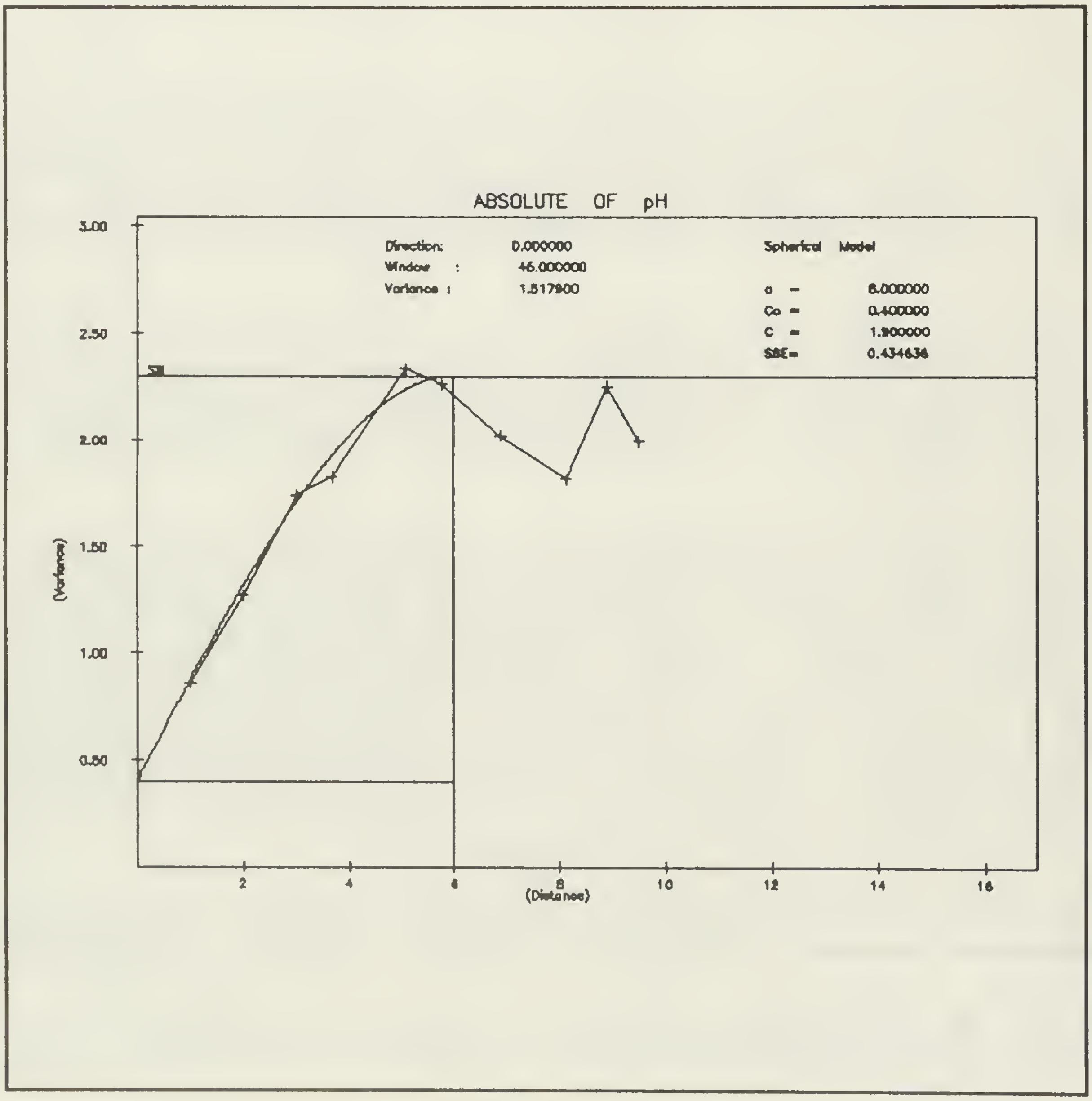

FIGURE 2 : EXPERIMENTAL VARIOGRAM

Area	Level	C_o	C	Rmax	Direction	Rmin	Direction
I	1	.15	.30	17.0	135°	11.0	45°
	2	.17	.10	2.5	All	2.5	All
	3	***	***	****	****	****	***
	4	***	***	****	****	****	***
II	1	.25	1.10	8.0	90°	3.5	0°
	2	.40	.80	12.0	90°	5.0	0°
	3	.40	.80	16.0	90°	3.0	0°
	4	.35	.95	10.0	90°	3.0	0°
III	1	.30	.30	3.0	All	3.0	All
	2	.40	1.00	4.0	All	4.0	All
	3	.40	.80	2.0	All	2.0	All
	4	.40	.70	2.5	90°	1.0	0°
VI	1	.15	.55	35.0	90°	7.0	0°
	2	.20	.50	30.0	90°	8.0	0°
	3	.25	.45	15.0	90°	6.0	0°
	4	.15	.55	10.0	15°	5.0	105°
V	1	.08	.08	6.0	All	6.0	All
	2	.22	.35	5.0	All	5.0	All
	3	.20	.35	4.5	All	4.5	All
	4	.25	.35	6.0	All	6.0	All
VI	1	.15	.75	6.0	75°	3.5	165°
	2	.30	1.30	16.0	90°	6.0	0°
	3	.25	1.75	18.0	90°	5.5	0°
	4	0.0	2.30	16.0	90°	5.0	0°

TABLE 3 : VARIOGRAM MODELS FOR pH VALUES

Area	Level	C_o	C	Rmax	Direction	Rmin	Direction
I	1	***	***	****	****	****	****
	2	***	***	****	****	****	****
	3	***	***	****	****	****	****
	4	***	***	****	****	****	****
II	1	.20	.55	4.0	All	4.0	All
	2	.60	.35	4.0	All	4.0	All
	3	10.	22.	6.0	90°	2.0	0°
	4	.30	.80	7.5	75°	3.0	165°
III	1	12.	6.	3.5	All	3.5	All
	2	.70	.60	16.0	90°	6.0	0°
	3	.70	.70	11.0	90°	5.0	0°
	4	.32	1.28	2.5	All	2.5	All
IV	1	.13	.08	3.5	90°	2.0	0°
	2	3.	3.	9.0	90°	3.0	0°
	3	.09	.20	6.0	75°	2.0	165°
	4	5.9	4.1	3.5	All	3.5	All
V	1	2.9	3.6	14.0	90°	3.0	0°
	2	.13	.05	4.0	All	4.0	All
	3	2.9	6.2	11.0	90°	2.8	0°
	4	***	***	****	****	****	****
VI	1	.40	1.80	11.0	90°	3.0	0°
	2	3.	12.	21.0	90°	3.0	0°
	3	1.25	16.	17.3	90°	7.0	0°
	4	3.	19.	20.0	90°	7.0	0°

TABLE 4 : VARIOGRAM MODELS FOR ACID BASE ACCOUNT

It should be noted that some of the ranges are very long. These long ranges are in many cases an artifact of variogram modeling. Many graphs show lower sill values in different directions. This is a zonal type anistoropy. This type of anisotropy is generally avoided in grid modeling and can usually be circumvented in the variogram modeling process, and was done in this study.

Since the kriging system only uses a portion of the mathematical model that is fit to the variogram curve, it is only essential to maintain a good fit on the portion of the model which is used. For this study, the distance was about 300 feet. Thus, although the sills and ranges for the long axes of continuity are both commonly artificially high, they maintain the best possible integrity through the usable portions of the model. The practioner should note that the model should fit well through a distance equal to no less than twice the search radius used in the kriging process.

DATA MODELING

To produce the contour maps of pH and acid base account values, point kriging was used. Block kriging was used to produce the estimates of the error for each of the variables. A total of 441 blocks was kriged for each of the 82 grid models. The 100 sample data points for each level in each area were used for the estimation. The sampled soil zones were treated as unique layered entities and as such no vertical information from above or below was used. Each grid model was fit with contours using a bicubic spline routine. Figure 3 shows a typical contour of acid-base account values.

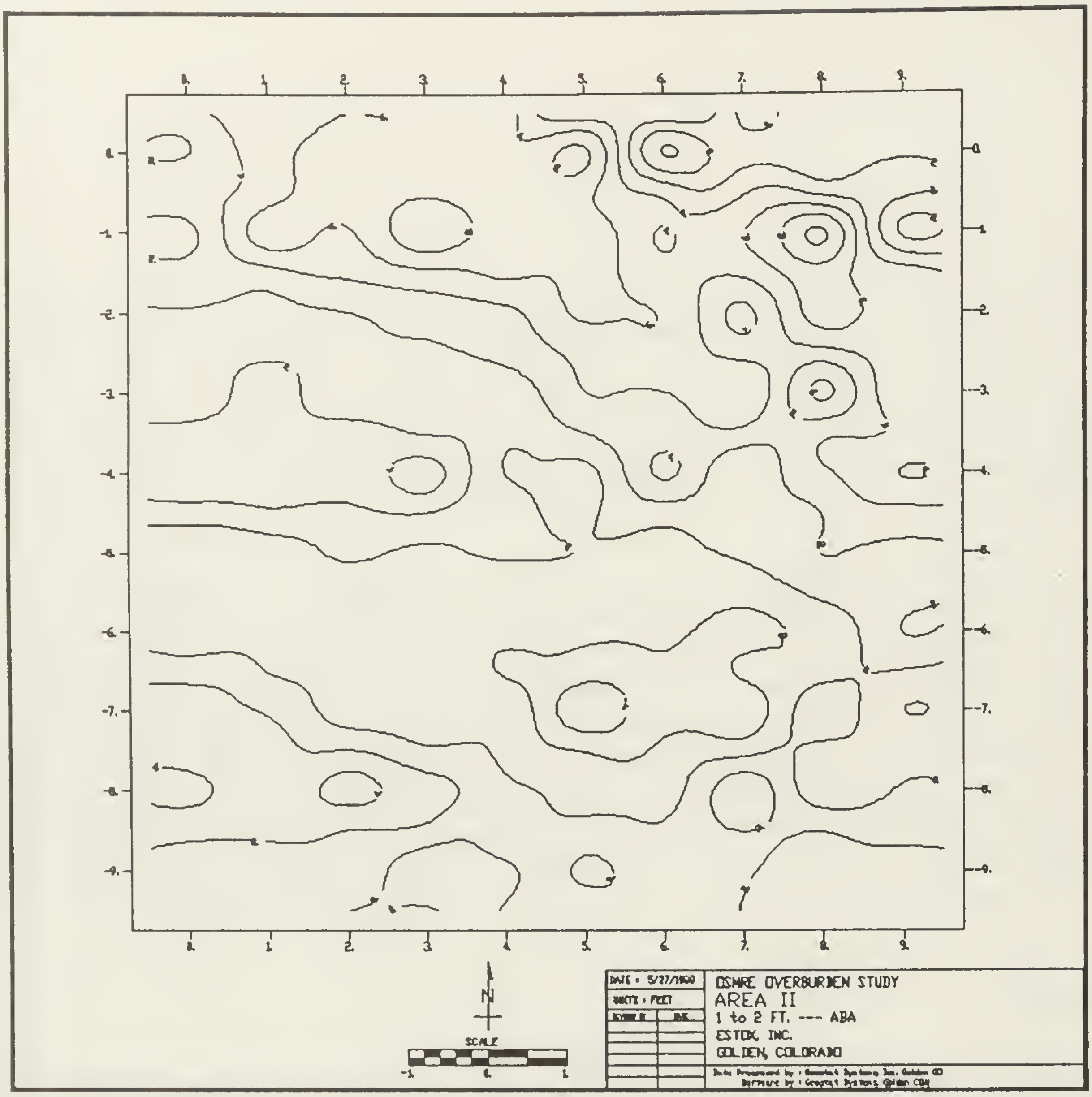

FIGURE 3 : CONTOUR OF ACID BASE ACCOUNT VALUES

The placement of the origin was of some significance in this study. One of the defined tasks was to calculate the percentage of the area which is below given threshold values. Many of the areas below the thresholds occur on the margins of the map.

The question, then, is to decide how far away from the outer edge of the data to extrapolate the values. This is analogous to the polygonal method of estimation. The further the extrapolation, the larger the percentage of below threshold values. Also, the further the extrapolation, the less confidence one has in the estimate. However, the variograms indicate that continuity extends beyond the edge of the map and thus the values should be extrapolated some distance beyond the edge. The error says it should not go too far. A value of 50 feet, equal to one half the grid spacing, was chosen. This is reflected in the contour maps as the contour lines end 50 feet from the last data point along the borders.

To obtain the percentage of the map area that was below the cutoffs for pH and ABA, the contoured areas were digitized. The total area below the cutoffs was divided by the total area of the contour grid to get a percentage value. The results of these computations are listed in Table 5. Generally the values were below ten percent, although values up to 28 percent were noted.

Area	Level	pH	Acid Base
I	1	.83	0.0
	2	.54	0.0
	3	0.0	0.0
	4	0.0	0.0
II	1	5.77	2.35
	2	8.37	4.05
	3	6.57	2.03
	4	9.60	4.26
III	1	4.11	1.26
	2	7.09	4.70
	3	11.76	9.52
	4	6.88	13.00
IV	1	0.0	0.0
	2	.06	0.0
	3	.19	.27
	4	.96	.28
V	1	0.0	0.0
	2	0.0	0.0
	3	.16	0.0
	4	.84	0.0
VI	1	23.96	18.52
	2	28.16	26.45
	3	26.21	24.23
	4	24.06	21.32

TABLE 5 : PRECENTAGE AREA CALCULATIONS

The kriging standard deviation for each variable in each area at each level was also contoured. Typical results are shown in Figure 4. The variance is lowest at the sample point and increases rapidly as one moves away from the sample. In the sampled portion of the grid, the variance generally reaches a type of "plateau" where small fluctuations occur but remains fairly constant over the large area. As one leaves the sampled area (on the edges of the map), variances again rise very rapidly indicating diminishing confidence in the estimates. The standard deviations derived from these variances can be applied to the contour lines to produce statistical confidence zones, called "fat" contours, at desired levels of confidence. This will greatly help reduce the number of errors made in the decision phase.

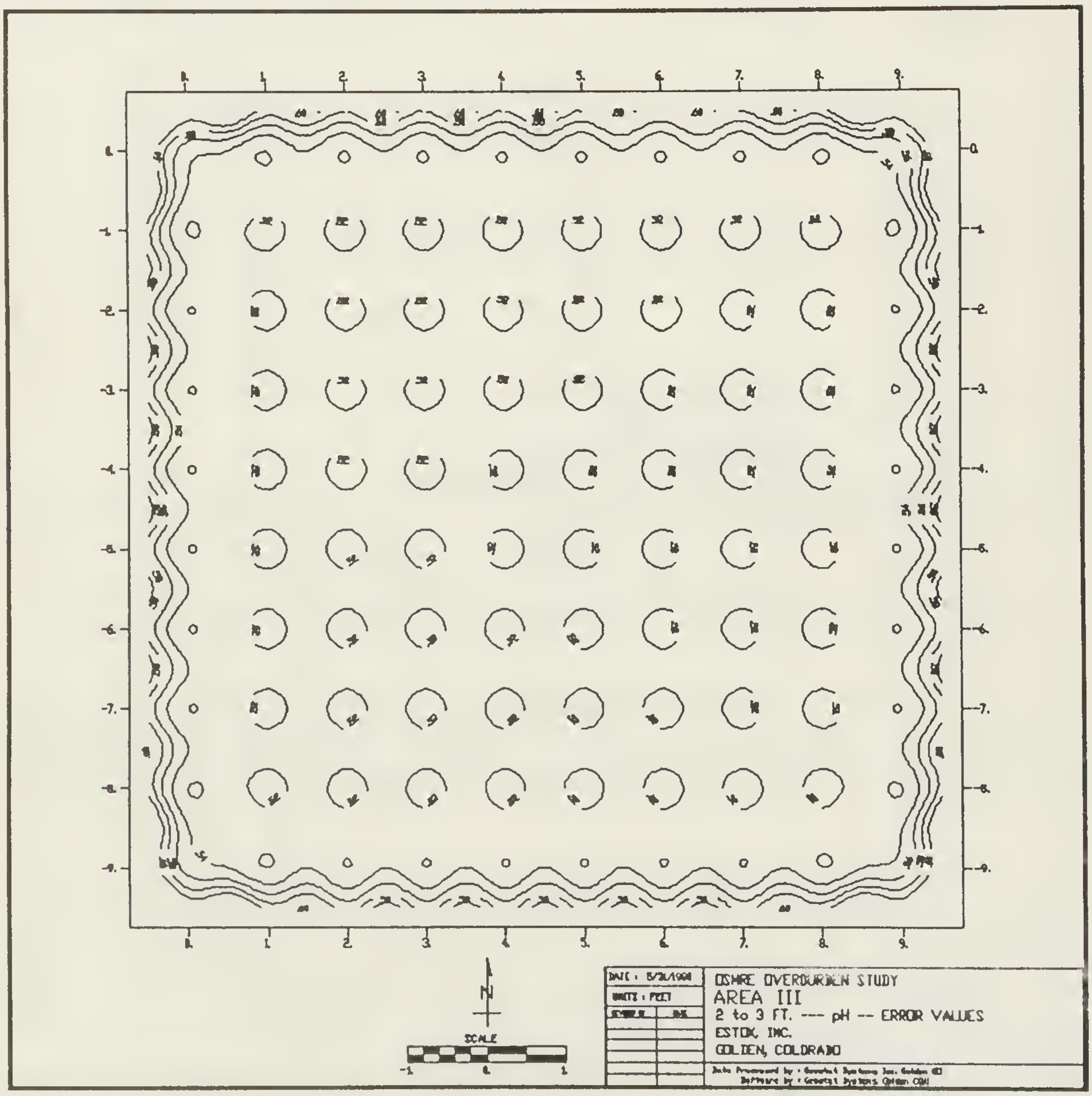

FIGURE 4 : CONTOUR OF pH ERRORS

SUMMARY

The volume and diversity of the data for this study revealed a great deal concerning the general nature of regraded spoil materials. Twenty four data sets of two variables each were used for the study. These data represented six unique mining situations and conditions and represented different soil levels within the area as well. These findings can provide a baseline for future work.

Geostatistical methods have demonstrated the ability to accurately map problem areas in minesoil and regraded spoils. Clearly definable spatial correlation has been demonstrated, and in most data sets rejects the hypothesis of randomness. This technique not only provides contour maps of threshold values but also yields an objective measure of uncertainty involved with the mapping.

The 100 x 100 foot regular sampling grid appears to provide good coverage for pH and acid base potential characterization in regraded spoils. This grid also appears to be adequate in most cases to define the variogram. Spatial continuity was commonly strongly anisotropic and displayed the best continuity in the direction of mining and more accurately mapped the areas below threshold values.

The statistical analysis proved once again the long-standing problem of averaging. No average value was below the threshold yet up to 28% of an area was below. This emphasizes the importance of spatial analysis versus blind statistical techniques. Unfortunately, it is not economically possible to sample on such dense grids over the entire regraded area. Thus, new and better field methods need to be developed. In the interim, spatial analysis can still assist in location of potential problem areas.

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USING X-RAY FLUORESCENCE SPECTROMETRY AND GEOSTATISTICS FOR MAPPING SOIL-METAL CONTAMINATION

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ABSTRACT

This paper describes an approach for mapping soil-metal contamination using a real-time analytical method and geostatistical mapping techniques. The approach was tested on a confidential project. Analytical-quality, field-mobile, energy dispersive x-ray fluorescence spectrometry (EDXRF) was used to determine metals in soils. EDXRF has some advantages over other analytical methods because the instruments are more mobile, soil extracts are not necessary and EDXRF gives multi-element analysis in a range of a few parts per million to 100%. To evaluate the use of EDXRF for this project, the EDXRF results were compared to atomic absorption (AA) results on 196 split samples and several standard reference materials. The results show that analytical quality EDXRF can provide detection limits, accuracy and precision necessary for hazardous waste site investigations.

Geostatistical analysis was used to produce contour maps of metals contamination and confidence. Combining the quick turn-around capabilities of EDXRF with geostatistics allowed for a sampling strategy that focused sampling efforts in areas of concern and where data confidence was inadequate. The sampling protocol was modified to reflect real-time analytical results and sampling was reiterated in certain locations to better define low concentration isopleths.

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INTRODUCTION

Background

Two relatively recent, independent developments, one in analytical chemistry and the other in statistical analysis, have significantly improved the methods of conducting studies of trace metals in the environment. Both developments utilize the dramatic improvements in power, size, and cost of microcomputers. Both are being applied to the cleanup of contaminated sites under CERCLA (the "Superfund" Act). The first development has been in energy dispersive x-ray fluorescence spectroscopy (EDXRF). In the last two decades with the development of semi-conductor technology, energy-dispersive x-ray fluorescence technology has made tremendous gains. With the advent of powerful personal computers, the EDXRF has been made powerful enough to handle the resolution of spectral parameters and mobile enough to go into the field.

The second development is the use of geostatistical analyses in pollution monitoring. Geostatistics were originally developed to deal with ore reserve estimation in the mining industry but it wasn't until the early 1980's that it was applied to pollution studies. Geostatistical analysis is now the preferred method for addressing soils contamination because, unlike classical statistics which are based on independent variables, geostatistics deals with spatially correlated variables such as metals in soils.

The state of the art for metals contamination studies uses on-site EDXRF to obtain multi-element analyses. The measured soil-metal values are input along with geographic coordinates into a geostatistical model which gives a contour map of metals contamination (isopleths) and a map of the estimated error. The error map and the isopleth map are used to design an iterative soil sampling program that addresses two regions of concern, areas at or near the regulatory action level and areas where data confidence is low. The geostatistics can be re-run on a daily basis and sampling iterations conducted until the extent of contamination is defined as accurately as required. The same approach could be used on a remediation project to demonstrate that a cleanup has been accomplished at a required level of confidence.

Regulatory Concerns

Metal contamination of soils is an important concern under CERCLA. Lead, for example, has been identified as a major contaminant on about 30% of superfund sites and arsenic, cadmium, chromium and zinc were each of concern on about 15% of the sites. Western metal mining and smelter sites in particular, where soil-metal contamination is the concern, often cover square miles and in some cases, encompass entire towns.

The EPA is under tremendous pressure to clean up these sites. The re-authorization of Superfund mandated that cleanup activities be completed on no fewer than 175 facilities by 1989 and 200 more by 1991.

The Contract Lab Program (CLP) is the primary method for analyzing superfund samples. The CLP labs are contractually required to perform inorganic analyses in 35 days and the cost is about $200/sample. This long delay means that enough samples must be collected in the first round of site sampling to adequately characterize the site, or crews must re-mobilize after the first set of results are obtained. Region I of the EPA has found that their site investigation time has decreased to 12 weeks from 45 weeks using onsite XRF (Furst et al. 1985).

To minimize these kinds of delays, the EPA has institutionalized a program (FASP--Field Analytical Screening Program) to facilitate on-site screening (Fisk et al. 1988). EDXRF is accepted by the EPA as a Level II analytical method according to their guidelines for Data Quality Objectives (DQO) for Remedial Response Activities (U.S. EPA 1987). According to that document the data for XRF are suitable for site characterization, evaluation of alternatives, engineering design and monitoring during implementation.

Energy Dispersive X-ray Fluorescence Spectrometry

EDXRF is a spectroscopic method where a sample is irradiated with x-rays, inducing the atoms present in the sample to emit their characteristic x-rays. Detection of these emissions by a solid state detector generates analog signals which are converted to digital form for acquisition by a microprocessor. Subsequent processing of the data provides spectral information which identifies the elements present in the sample and the intensities of the identified elements. Concentrations are then calculated from these intensities by fitting the data to stored calibration curves which have been computed previously from analyzed standards or from theory (Leyden 1984).

EDXRF is ideally suited to soil-metals contamination. First, the samples require minimum preparation. Unlike Atomic Adsorption (AA) or Inductively Coupled Plasma (ICP), no acid extraction is necessary; drying, sieving and probably grinding is necessary for the highest precision. Unlike AA, EDXRF has a dynamic range that corresponds to the typical soil-metal values found in contaminated soils. AA is restricted to ppm levels but the EDXRF range is a few ppm to 100%. The

detection limits for the analytical quality instruments are not as low as AA or ICP but are in the range of a few to 10 ppm for soil-metals; regulatory levels of concern are high enough (e.g., 500 ppm Pb, 50 ppm As, 3 ppm Cd) that an analytical quality EDXRF can readily detect these levels. Because sample preparation is minimal and EDXRF can handle the dynamic range typically found in contaminated soils, sample throughput (samples per day) in a field mobile lab is approximately 25 samples per 8-hour day.

For this study, a Tracor Spectrace 6000 (Tracor XRay, Inc., Mountain View, CA) was used. It is an analytical quality EDXRF with a high resolution detector and an IBM PC based microcomputer. The Spectrace 6000 uses a fundamental parameter program that does not require site specific calibration standards. The instrument can be set up in a mobile lab. In this study the instrument was in a fixed based lab.

A number of investigators have been using XRF for metals sites investigations and finding acceptable agreement between XRF and CLP methods. Perlis and Chapin (1988), using a Tracor 6000 found very good correlation (r = 0.98 and 0.97, respectively) for co-located samples for Cu and Pb. Other metals had lower correlations (As 0.89 and Cr 0.81) but they found the approach successful. Furst, Trillinghast and Spittler (1985) using a Kevex 7000 found "good agreement" between XRF and CLP and concluded it "supports the use of XRF metal screening as a powerful analytical tool." Chappell, Davis and Olsen (1987) using a Columbia X-Met 840 running as many as five metals at three different sites found three significant differences out of ten comparisons between XRF metals and CLP metals in sets of samples, but seven out of ten showed no significant difference.

Geostatistics

Geostatistical analysis provides a method for designing soil sampling strategies based on spatially correlated variables. Geostatistical methods are useful for site assessment and monitoring situations where data are collected on a spatial network of sampling locations, and are particularly suited to cases where contour maps of pollutant concentration are desired.

Geostatistics is based on a semi-variogram model of the spatial relationship of samples to one another and kriging. Kriging is a weighted moving average method used to interpolate values from a sample data set onto a grid of points for contouring. The kriging weights are computed from the variogram, which measures the degree of correlation among sample values in the area as a function of the distance and direction between samples.

Kriging has a number of advantages over most other interpolation methods. Kriging smooths, or regresses, estimates based on the proportion of total sample variance accounted for by random "noise." The noisier the data set, the less individual samples represent their immediate vicinity, and the more they are smoothed. The kriging weight assigned to a sample is lowered to the degree that its information is duplicated by nearby, highly correlated samples (called declustering). This helps mitigate the impact of oversampling "hot spots."

Kriging also accounts for anisotropy; when samples are more highly correlated in a particular direction, kriging weights will be greater for samples in that direction. Given a variogram representative of the area to be estimated, kriging will compute the most precise estimates possible from the available data. In practice, this is only approximated, as the variogram must itself be estimated from the available data.

Geostatistics provides a method to balance precision, and cost in sampling. The first phase of a geostatistical approach is a sampling survey, using a widely spaced grid, to collect enough information to define a semi-variogram which describes the ranges of influence and orientation of the correlation structure of the pollutant spill or plume. The second stage is a census of the suspected area with grid shape, sizes and orientation dictated by the semi-variogram. The program can comprise many iterations with increasing emphasis on areas near the action level and where the errors are unacceptable (confidence is low).

Indicator kriging is a special type of kriging that uses the presence or absence of contaminants above or below a critical value rather than actual concentrations. The indicator approach is especially useful in highly skewed and highly variable spatial distributions. In indicator kriging, the probability for the unknown concentration to exceed any given threshold can be derived and contour-mapped. Journel (1984) refers to them as "confidence interval-qualified estimates"; similarly, the risks (Type A and B) of making a wrong decision to clean or not to clean can be assessed and mapped. The use of an indicator approach requires that an action level (e.g., 1000 ppm Pb) be decided on by the regulatory authority before the indicator program can be run. Indicator kriging was not used in this study because action levels had not been specified by the regulatory authority.

RESULTS

Site Sampling

Four inorganic soil contaminants were evaluated for this study: lead, arsenic, zinc and cadmium at four sampling depths. Approximately two hundred samples were analyzed and the EDXRF results of these samples were presented as contour maps using geostatistics to describe the analyte contamination plume. EDXRF results were compared to results obtained for sample splits submitted for AA analysis at an independent laboratory. Accuracy and precision of the EDXRF method were compared to the AA method using standard reference materials and soil samples submitted in triplicate to both laboratories. The EDXRF analytical method and interpretation of the data are described in more detail by Harding and Walsh (in press).

Sampling of the site was performed using EPA approved protocols. Forty-three (43) cores were collected and were partitioned into four depth levels: surface to 2"; 2" to 6"; 6" to 12"; and 12" to 18". At the site, samples were first homogenized and then split into two fractions. One was submitted for EDXRF analysis and the other sent to an independent lab for AA analysis. The independent laboratory used EPA SW-846 methodology to determine contaminant concentrations in the soil sample split.

Sample Preparation

Sample preparation for the EDXRF analysis consisted of drying the sample for 4 m in a microwave oven followed by sieving the dried sample to 2 mm. Sieving removes large foreign objects such as pebbles and sticks. Drying the sample was required due to the variable moisture content in the submitted soils; some surface samples had the consistency of mud. The sieved soil was then ground in a Spex shatterbox grinder (Spex Ind., Edison, NJ) using tungsten carbide cups for 2 m.

EDXRF Analysis

Two sets of excitation conditions were employed to determine seven elements in the soil samples, four of which are of specific environmental concern: Zn, As, Pb, and Cd. Figure 1 is a mid Z spectrum of a soil sample that was found to contain 125 ppm As, 1100 ppm Pb and 729 ppm Zn.

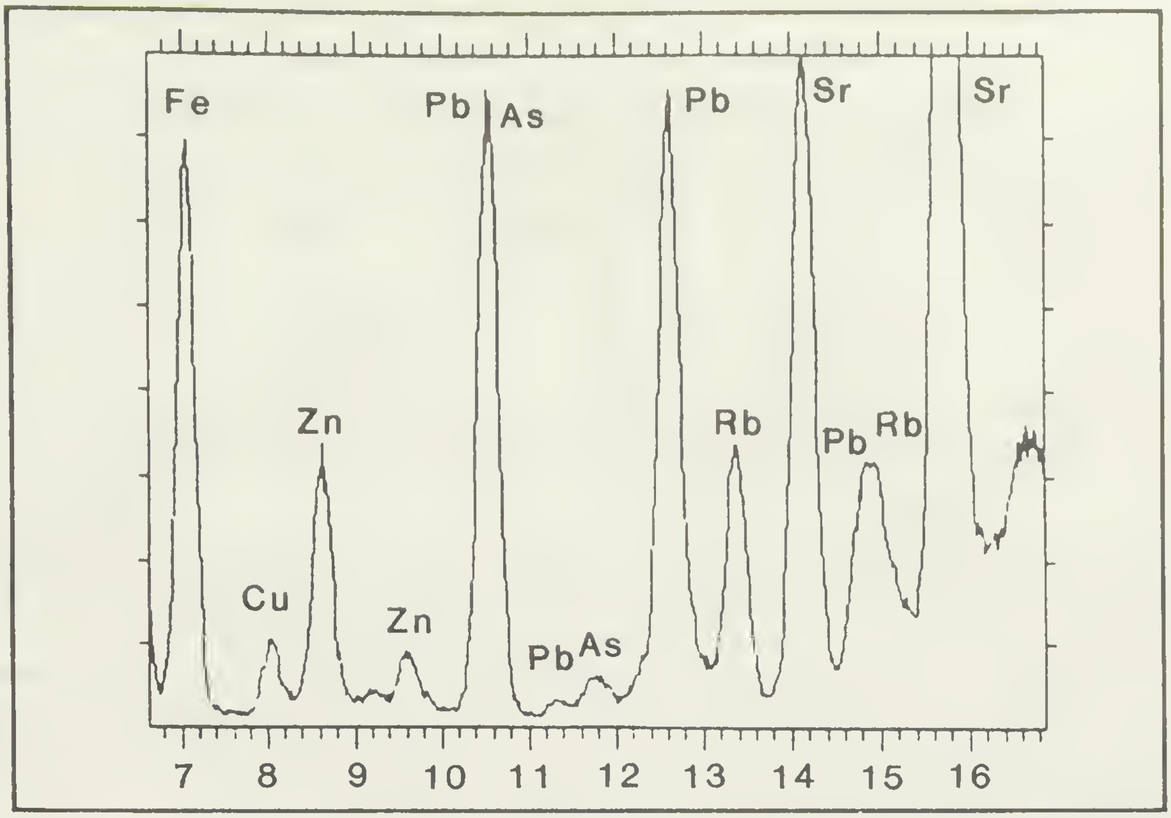

Figure 1. Mid Z spectrum of a soil sample containing 1100 ppm Pb, 729 ppm Zn and 125 ppm As. Vertical full scale is 2,000 counts.

The soil characterization method was standardized using four standard reference materials (SRM): NBS 1648 (urban particulate); NBS 2704 (river sediment); SO-1 and SO-3, two soil standards available from the Canada Centre for Mineral and Energy Technology. Standards labeled NBS are available from the National Institute for Standards and Technology (NIST). These SRMs have certified concentrations of Fe, Mn, Cu, Zn, Pb and Cd.

A fundamental parameters method was employed as the data treatment scheme and used the certified concentrations of Fe, Mn, Cu, Zn, Pb and Cd in the four standard materials. The method for standardization allows well characterized SRMs to be the basis of analyte sensitivities and eliminates the need for site specific soil standards. It permits accurate analyte concentrations to be determined in samples with wide matrix variation without restandardization. Theoretical analyte sensitivities can also be computed by the fundamental parameters routine when a standard with a certified analyte concentration is not available.

Detection Limits

For the analytes of specific environmental concern (As, Cd, Pb, Zn), the lower limits of detection (LLDs) range from 4-19 ppm. Calculated LLD values could be improved with longer spectrum acquisition times and alternate excitation conditions.

Table 1. Lower limits of detection for the analytes of interest.

Analyte	LLD	Analyte	LLD
Mn	21 ppm	Pb	7 ppm
Fe	19 ppm	As	12 ppm
Zn	19 ppm	Cd	4 ppm

EDXRF and AA Comparison

Results for the determination of four analytes by EDXRF in 196 samples were compared to independent AA analysis results in order to evaluate the level of agreement between the two methods. Table 2 lists the correlation plot data for the analytes in terms of actual slope, intercept, errors, and the correlation coefficient of the fit. Each analyte correlation plot included approximately 150 data points.

Table 2. Correlation plot data comparing EDXRF to AA results for the four analytes of environmental interest.

Analyte	Slope	Intercept	Correlation Coefficient
Pb	1.01 $\pm$0.03	10.0 $\pm$13.8	0.96
As	1.08 $\pm$0.05	0.98 $\pm$3.54	0.92
Cd	1.02 $\pm$0.03	3.09 $\pm$2.19	0.94
Zn	1.02 $\pm$0.02	63.0 $\pm$13.6	0.98

As shown in Table 2, slopes of the plots for Pb, Cd, Zn and As are within 8% of unity and all correlation coefficients greater than 0.92. The calculated slope near 1.00 and correlation coefficient greater than 0.90 indicates good agreement between the two analytical techniques. Figure 2 is a plot of 138 data points in the range of 0 to 1600 ppm Pb; figure 3 is a plot of 125 data points in the range of 0 to 350 ppm Cd. EDXRF and AA analyzed samples for lead and cadmium and indicate good agreement between the results of the two methods for these soil contaminants.

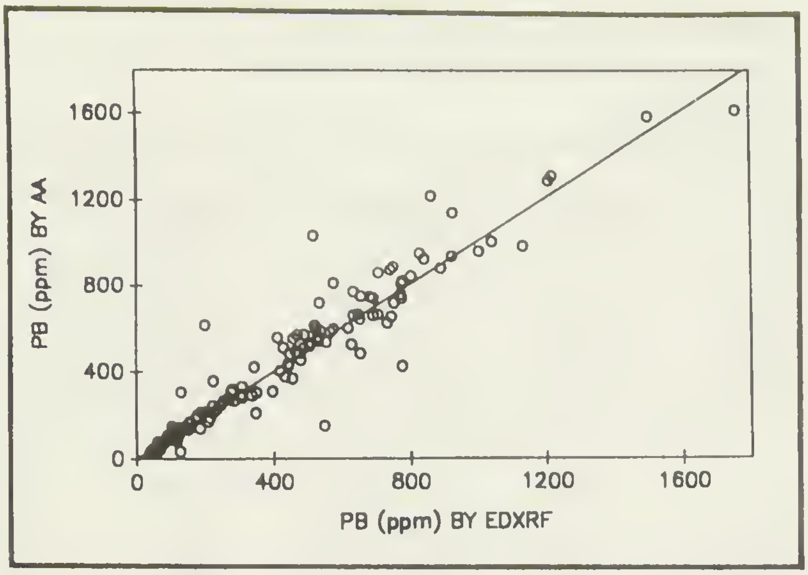

Figure 2. Plot of PB by EDXRF versus PB by AA

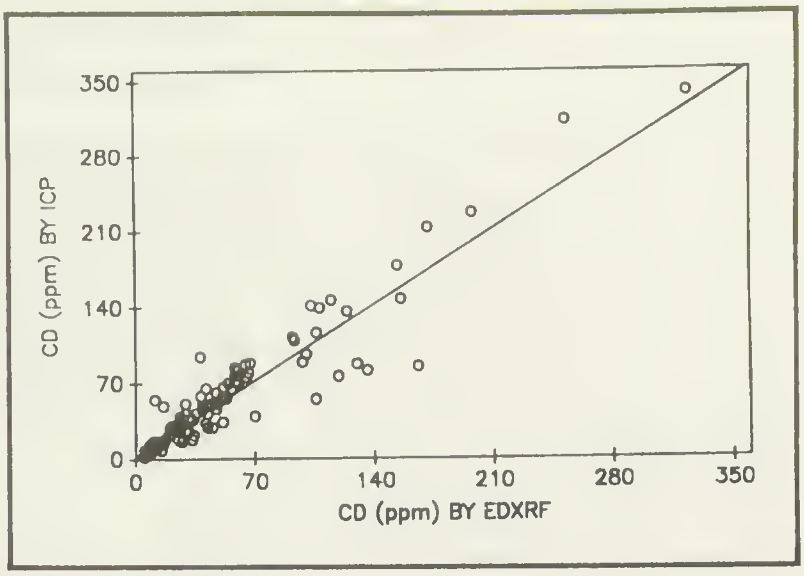

Figure 3. Plot of Cd by EDXRF verses CD by AA.

To evaluate the accuracy provided by the EDXRF method, two SRMs were submitted as unknowns for EDXRF analysis as well as being submitted to the AA lab for analysis. Table 4 contains the results for lead and zinc for two SRMs, SO-1 and SO-2. SO-1 was used in the EDXRF standardization method and the EDXRF results show good agreement with the certified concentrations. The AA analysis for Pb in SO-1 is in error by about 95% (relative percent difference - RPD). EDXRF analysis of SO-2, which was not used in the EDXRF method standardization, provides results that are in good agreement with certified values. The independent AA analysis for zinc in SO-2 is biased low by a factor of 56%.

Table 4. Results of the analysis of two SRMs by AA and EDXRF methods. All values in ppm.

Sample	Analyte	AA	RPD	EDXRF	RPD	Certified
SO-1	Pb	41	95%	14	33%	21
	Zn	129	12%	147	1%	146
SO-2	Pb	19	10%	17	19%	21
	Zn	55	56%	123	1%	124

Sample-to-sample precision for both the independent analysis and EDXRF was evaluated by submitting three samples a total of three times to each laboratory. Table 5 shows the results for the two methods along with the relative standard deviation of the three replicate analyses. Note that Cd in Sample C was only reported by EDXRF to the nearest 1 ppm and three values of 9 ppm Cd were determined, hence the zero standard deviation for the three replicates. EDXRF sample-to-sample repeatability is within 10% (relative standard deviation) in all but one case (as in sample C) and is comparable to precision provided by the AA methods.

Table 5. EDXRF and AA results for three soil samples each analyzed in triplicate.
Mapping

Sample	Element	AA	RSD	EDXRF	RSD
A	As	45 ±4	9%	41 ±3	7%
	Cd	20 ±2	10%	31 ±3	10%
	Pb	286 ±28	10%	312 ±12	4%
	Zn	185 ±15	1%	134 ±10	7%
B	As	17 ±3	18%	14 ±1	7%
	Cd	80 ±6	8%	58 ±4	7%
	Pb	141 ±15	11%	158 ±3	2%
	Zn	556 ±39	7%	529 ±46	9%
C	As	17 ±1	6%	19 ±4	21%
	Cd	10 ±0.9	9%	9 ±0	0%
	Pb	117 ±8	7%	142 ±14	10%
	Zn	173 ±26	15%	128 ±3	2%

Mapping

Figure 4 is a contaminant map showing cadmium in ppm in surface soils (0 to 2 inches) from EDXRF data for a portion of the study area. The final map is the result of several sampling iterations conducted in areas of concern. The sampling program was modified during sampling to reflect the results of earlier sampling iterations. Sample depth was increased and deeper samples were subdivided to provide better delineation of contamination depth.

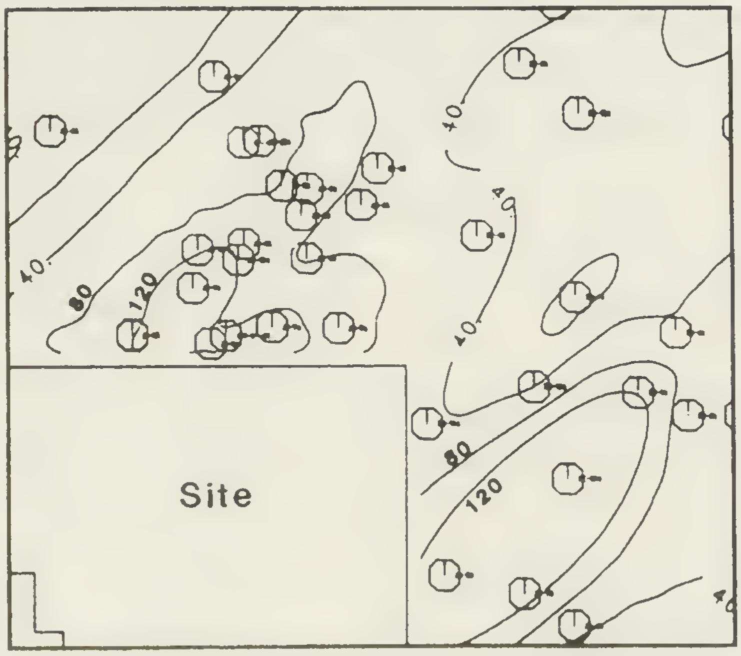

Figure 4. Kriged estimates cadmium levels in surface soils (0 to 2 inches). Contours in ppm.

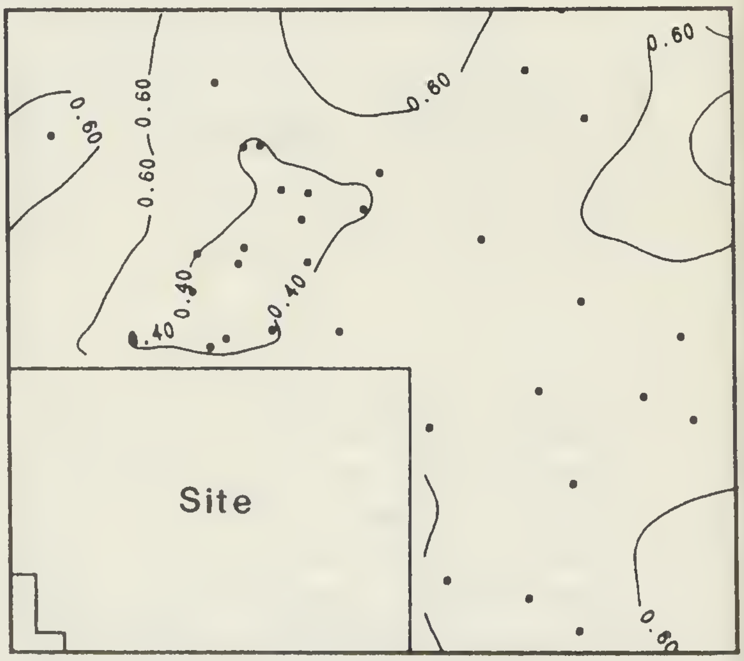

Figure 5. Cadmium kriging error of estimation in surface soils (0 to 2 inches). Contours in coefficient of variation kriged best estimates.

Figure 5 is the error map for a portion of the study area. The error map illustrates the precision of the kriged estimates. It is a contour map of the kriging error of estimation expressed as coefficient of variation. Coefficients of variation range from 0.40 to 0.60, reflecting a significant heterogeneity in the contaminant distribution. More intensive sampling would probably be required before remediation could occur.

CONCLUSION

EDXRF analysis of soil-metals provides accuracy, precision and detection limits adequate to map metals contaminated soils. The EDXRF instrument used in this study provides some advantages over AA and ICP in that the instrument can be set up in a mobile lab on-site and soil samples require minimum preparation. The data were analyzed and mapped using geostatistical analysis, a powerful methodology that provides an estimate of the confidence in the mapping. Combining the quick turnaround capabilities of EDXRF with the capabilities of geostatistical analysis allows for a sampling strategy that focuses on areas of concern and areas where the confidence in the mapping is inadequate.

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Planning, Rehabilitation and Treatment of Disturbed Lands
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APPLICATIONS OF GIS IN MINERAL EXTRACTION AND HAZARDOUS WASTE PLANNING

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ABSTRACT

Geographic Information Systems (GIS) are powerful application tools for mining, mine permitting, and mine reclamation. A GIS is a computer based system which can capture, store, edit, manipulate, integrate and display on a map multiple "layers" of data as geographic reference material. With GIS, both mine maps and large numbers of spatially related data files can be kept continuously updated. The interactive capabilities of different mapped and filed information create new capabilities for environmental management at mine sites.

Information required for mine feasibility assessments and environmental impact studies can be stored and manipulated in both tabular and map formats. Land ownership, land use, soils and vegetation can be stored separately and output in any combination of overlays. Topography, geology, hydrology, overburden thickness and piezometric surface elevations can be added to the data base and mapped.

Alternative scenarios of mine operation may be analyzed and evaluated using GIS. Different sequences of cut and fill can be mapped in time step fashion and examined for efficiency, environmental impact and ease of reclamation.

A second example shows how GIS is used in a hazardous waste investigation. Hydrogeologic parameters such as top of aquifer elevation, aquifer thickness, piezometric surface, hydraulic conductivity and storativity can be mapped together with confining bed characteristics and contamination sources. Concentrations of naturally occurring or contaminating chemical species can be contoured and mapped to show plume configurations. Optimum monitor well placement can be enhanced by having the best possible visualization of spatial variability in hydraulic and chemical characteristics. GIS data bases can also be integrated into groundwater flow models.

Design of data base structures for GIS analyses are discussed, as well as system design parameters for various sized mining coverages. Spatial analyses particularly appropriate for mining applications are also presented.

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DEVELOPMENT OF A DATA BASE SYSTEM TO AID THE WDEQ IN THE EVALUATION OF SURFACE MINING PERMIT AND RENEWAL APPLICATIONS

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ABSTRACT

Western Research Institute (WRI) is developing a data management system for the Wyoming Department of Environmental Quality (WDEQ), Land Quality Division (LQD), under a cooperative agreement with the United States Department of Interior (DOI), Office of Surface Mining (OSM). The management system is being developed primarily to store hydrologic data, including spring and stream flow, groundwater level, ground and surface water quality, and aquifer test data. The data are used by the WDEQ to assess the probable hydrologic consequences and the cumulative hydrologic impact of surface coal mining operations. The majority of the data was collected for the mining companies for the purpose of completing permit or renewal application requirements.

By evaluating WDEQ's data management needs, data requirements, and implicit data relationships, WRI determined the objects, the characteristics of the objects, and the relationships between objects that must be represented in the data base. To a great degree, the data set has hierarchical characteristics; however, many of the relationships can only be modeled by a relational structure. Therefore, a relational data base software package, ORACLE, was chosen to develop the data base.

The data base consists of tables that describe each object and that map complex relationships between objects. Within the data base an entity is identified by its location. The data from sampling points (e.g., wells, sediment ponds) are separated into tables and predefined retrieval sets (views) such that the user can select data based on the name of the sampling point(s), even though two or more sampling points may have the same name.

WRI is developing procedures within ORACLE to enter and retrieve data in a manner that reduces errors and is understandable and useful to the user. Testing and streamlining the data is an on-going process, as is the development of a user's manual. Upon completion of the data management system, WRI will offer a course to the WDEQ and others on how to use and protect the system.

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INTRODUCTION

Western Research Institute (WRI) is developing a data management system for the Wyoming Department of Environmental Quality (WDEQ), Land Quality Division (LQD), under a cooperative agreement with the United States Department of Interior (DOI), Office of Surface Mining (OSM). The management system is being developed to store hydrologic data, including spring and stream flow, groundwater level, ground and surface water quality, and aquifer test data, primarily from surface coal mines. The data are used by the WDEQ to assess the probable hydrologic consequences and the cumulative hydrologic impact of surface coal mining operations. The main objective of the project is to create an operationally efficient, protected system in which the data structure is properly modeled, and data are entered and retrieved in a manner that reduces errors and is understandable and useful to the user.

DETERMINING THE STRUCTURE OF THE DATA AND THE NEEDS OF THE USER

This is the most important and complicated step in developing a data management system. It is also an activity that never reaches completion because the needs of the user continually change. Also, the designer's understanding of the data structure improves as the user evaluates the system and the designer adjusts the system to meet the changing needs of the user.

Determining the structure of the data and the needs of the user are integrated, simultaneous activities. Through conversations between the system designer and the user, the designer determines the needs and expectations of the user. These discussions provide the designer with the user's view of the data structure, and with insight on how to proceed with the process of developing a data management system that is understandable and useful to the user.

The steps required to define the structure of the data are as follows:

- Determine the types of entities (e.g., wells, mines) that are described in the data. "An entity is a person, place or thing...about which the (data management) system is to maintain, correlate, and display information" (Relational Systems Corporation 1985).

- Determine the attributes of each entity type (e.g., the depth of completion is an attribute of all wells), particularly the attribute that uniquely identifies each entity within an entity type (e.g., location may be used to distinguish one well from another)

- Determine the relationships between entity types (e.g., between mines and structural basins--many mines have an effect on the hydrologic system within a structural basin, but a mine exists in one and only one structural basin)

The entities, attributes, and relationships that are of interest to the user must be represented in the data base.

The types of entities that are described by or mentioned in WDEQ's data are numerous and include basins, streams, mines, lakes, natural ponds, reservoirs, aquifers, springs, permanent impoundments, stock ponds, sediment ponds, water quality and other parameters, mining and other companies, and government organizations including regulatory agencies. Time is also an entity. In addition to this list, there are entities that exist within entities, including wells that are completed within a geologic unit (possibly an aquifer), stream stations that are located at different points along a stream, and an infinite number of sampling locations that exist within a water body.

Determining the attributes that uniquely identify each entity within an entity type (e.g., each well within a set of wells) has been a more complex process than originally anticipated. Attributes of this type must exist; otherwise, it is impossible to associate a data value with one and only one entity. Objects with unique names can be identified using the name of the object; however, most of the objects in WDEQ's data set are not guaranteed to have a unique name.

Stationary objects can be identified by their location (e.g., latitude and longitude if the object is a point), the assumption being that no two stationary objects can exist at the same place. The objects in WDEQ's data set are stationary, and with a few exceptions, those objects that are not guaranteed to have a unique name are considered to be points. However, the location of many objects is often unspecified in WDEQ's data or insufficiently precise to uniquely identify an object.

In the first draft of the data base, we were concerned with data from sampling points that are associated with one and only one mine. That is, the sampling points that were of interest are not associated with more than one mine or with nonmining operations. Because many locations are unknown, the objects were uniquely identified using other attributes. For example, we used the combination of the well name and the permit number of the mine to uniquely identify a well because the data (of interest) supports the assumption that this combination provides a unique identifier. The data (of concern) supports the assumption that the names of wells are unique within a group of wells associated with a single mine. Inherent is the assumption that mine permit numbers are unique within the state.

In the most recent draft of the data base, the location is used to identify stationary objects that are not guaranteed to have unique names. Those objects that are areas or volumes (e.g., lakes) are identified by a location within the boundaries of the object. The locations will be determined by digitizing the maps that are provided by the mining companies and other sampling point owners. Location provides a means to uniquely identify objects within the data base, but the fact that the exact location of an object is often unknown to the user has not been addressed. This problem is handled by the data base in a manner that is discussed later in this paper.

Determining the relationships between entities has also been complicated. A mining company may submit data from points owned by any organization, including federal agencies, other mining companies, private citizens, Indian reservations, etc. In addition, data may be collected for nonmining organizations (e.g., the WDEQ) from locations that may or may not be owned by mining companies. To further complicate matters, a sampling point is not necessarily associated with one and only one mine, as was anticipated when developing the first draft of the data base. A sampling point may be associated with more than one mine, or it may not be associated with any mine. As a result, a relationship between a sampling point and a mine does not necessarily exist. Rather, there is a relationship between a sampling point and an owner. There are also relationships between the data from a sampling point and the organizations for whom data are collected, the sites that are described by data, time, and so on.

Thousands of similar relationships exist in the OSM/WDEQ data management system and many have been similarly difficult to define. The OSM has requested that options be added to the data management system to store all data that will aid in determining the probable hydrologic consequences and cumulative hydrologic impact of a mining operation, including data from sampling points that are not associated with a particular mine.

DATA BASE TYPE

The structure of WDEQ's data set is "object oriented" meaning that it has both hierarchical and relational characteristics. To a great degree, the data set is hierarchical in nature. For example, many basins are located within a state; many mines are located within a basin; many sampling points are located in (or associated with) a mine; many parameters are measured at a sampling point; and so on. However, there are many relationships between entities that cannot be efficiently represented by a single hierarchical structure. As an example, wells and mines are both associated with geologic units. A well is completed (typically) in one and only one geologic unit; a mining company mines through one or more geologic units; and one or more mines may mine through a single geologic unit. These relationships can be represented by a hierarchical structure, but much information must be repeated, making the storage requirements astronomical.

In addition, as mentioned earlier, a sampling point is not necessarily owned by a mining company or sampled for the purpose of evaluating conditions at a mine. A relational data base is necessary to efficiently model the relationships between a sampling point, its owner, the sites about which the sampling point provides information, and the organizations for which data are collected. Considering the number of relationships that exist in this application that cannot be efficiently represented by a hierarchical structure, a relational data base software package was chosen to develop the data base.

A relational data base consists of data tables that describe each entity in the data set and create pathways for examining relationships between entities. A data base table, like a table in a report, "is a two-dimensional representation of data consisting of columns and rows" (Relational Systems Corporation 1985). For example a table that describes people may contain the name, social security number, and address of each person. The entity type is people; each entity described in the table is a person; and the attributes of each entity are name, social security number, and address. An attribute corresponds to one or more columns (e.g., a location corresponds to two columns, latitude and longitude), but a column corresponds to one and only one attribute. A row (or record) contains the data for one and only one entity, in this case, a person. The OSM/WDEQ data base consists of over one hundred tables.

ORACLE, a relational data base software package, was used to develop the data base. The decision to purchase a relational software package was very sound, because it permits modeling of both relational and nonrelational structures. WRI does not wish to promote any particular software package (see ACKNOWLEDGEMENTS AND DISCLAIMER); however, the capabilities of ORACLE have allowed WRI to meet the main objective of the project as specified in the introduction.

CREATING THE DATA BASE

Two types of tables are represented in the OSM/WDEQ data base, prime and associative tables. In order to understand the definition of prime and an associative table, we first must understand the definition of a primary and a foreign key.

"A <u>primary key</u> is a column or group of (non-superfluous) columns that insures the uniqueness of rows within a table" (Relational Systems Corporation 1985). Just as every entity must have an attribute with a unique value, every table must have a primary key. Primary keys are created using the data base software. A restriction, the "not null" restriction, is placed on each primary key to prevent a null value from being stored in the primary key columns, and a unique index, composed of each primary key column, is created for each table. (Like an index in a book, an index on a data base table also tends to decrease the amount of time necessary to find data in the table.)

"A <u>foreign key</u> is a column or group of columns that is not the whole primary key of a table, but is based upon the same domain(s) as the primary key of the same, or some other, table" (Relational Systems Corporation 1985). Foreign keys are one mechanism for modeling relationships between entities because they create links between tables.

To return to the discussion of table types, a prime table is one with a primary key that consists of a single attribute, and an associative table is one in which the primary key consists of more than one component, each of which is a foreign key. More specifically, each primary key component of an associative table is the primary key of a prime table and may be a primary key component of or an attribute in some other table.

Except under special circumstances, a table is either prime or associative.

Prime Tables

Approximately one-third of the tables in the OSM/WDEQ data base are prime. Each prime table contains data that describe an entity type. For example, there is a table that describes each well in which the completion depth, the surface elevation, etc., are stored. "Prime tables always model entities; entities are always modeled in prime tables" (Relational Systems Corporation 1985). The attribute that uniquely identifies an entity within an entity type is the primary key of the table.

As mentioned earlier, location is the attribute that is used in the current data base to uniquely identify entities that are not guaranteed to have a unique name. Thus, location is the primary key of many prime tables in the OSM/WDEQ data base. Until the digitizing effort is complete, WRI will not place the not null restriction on the primary key columns of these tables. This will allow WRI to load data from sampling points of unknown location while the digitizing effort is in progress. Once location values are available for every sampling point, the not null restriction will be implemented.

A unique, arbitrary, integer number is assigned in most of the prime tables to each entity. The prime tables in which this occurs are ones in which the primary key requires a lot of storage space (e.g., location). The integer numbers replace their corresponding primary key values in all other tables. For example, if well location is an attribute in a table (other than the prime table in which wells are described), each well location value is replaced by its corresponding integer value. The purpose of this is to reduce the amount of space required by the data base. For reasons discussed in the next major section, the user does not need to know the integer value that corresponds to a primary key value, and the integer values are unique only within an entity type (e.g., a well and a stream may be assigned the same "unique" number)

The majority of the prime tables in the OSM/WDEQ data base are also look-up tables, meaning that the data are from a source other than the data set that is being modeled. For example, a table that describes analytical methods may contain the precision, accuracy, and detection limit of each method. This information cannot be found in WDEQ's data set; rather, it is found in references that describe the methods. The OSM/WDEQ data base includes look-up tables that describe analytical methods, parameters, the types of dams, the possible methods for measuring flowrate, etc. The table that contains the last integer assigned to each type of entity is also a look-up table.

Associative Tables

Approximately two-thirds of the tables in the OSM/WDEQ data base are associative. The majority of these map changes over time. For example,

there is a table that lists each parameter value measured in each well over time. Associative tables that map changes over time are known as history tables. A history table has at least one primary key component that indicates a point in time.

The remaining tables in the OSM/WDEQ data base are associative tables that map complex relationships between entities that do not include time. For example, there is a table in the OSM/WDEQ data base that lists the streams that flow in each structural basin--a single stream may flow in more than one structural basin, and more than one stream may flow in a single structural basin.

Of particular importance are those tables that list the other names by which an entity is known. The name of an entity may change with time or an entity may be known by several names at the same time. In the case of sampling points, the names in the prime tables are the ones most commonly applied to each sampling point. If the user cannot find an entity of a particular name in the entity's prime table, the user may refer to the "other names" tables to determine if the entity is known by another name. Streams, formations, and geologic units present a more difficult problem because they may have different names at different locations. For example, the Wind River in the Wind River Basin of Wyoming and the Bighorn River in the Bighorn Basin of Wyoming are one river. Entities of this type have a record in the entity's prime table for each name. The other names tables may be used to correlate data from different locations within or along the same entity.

Sampling Point Data Model

Data from sampling points (e.g., wells, sediment ponds) make up the core of WDEQ's data set. The manner in which these data are separated into tables and the views of the tables that are available to the user deserve additional discussion.

Data from sampling points are separated into sets of tables according to the sampling point type. That is, data from wells are stored in one set of tables; data from sediment ponds are stored in another set; and so on. Each set of tables contains two prime tables: one describes the sampling points that are owned by mining companies and the other describes the sampling points that are owned by nonmining organizations. There are also two sets of history tables for each sampling point type: one set contains data that were collected for the purpose of evaluating conditions at a mine and the other contains data that were collected for other purposes. Within each set of history tables there are tables that contain flow, groundwater level, aquifer test and/or water quality data, depending on the type of sampling point. Flow and water level data are contained in single tables, whereas aquifer test and water quality data are separated into several tables.

The data are also separated into views. A view is a virtual table, and views are created so that the user can examine the data displayed in a manner that is intelligible to the user, rather than in the manner that the data are stored. For example, in the views that were created for the

WDEQ, the names and locations of entities appear in place of the unique integers that identify the entities in some tables. Views contain no information of their own; rather, they contain references to a portion of a table or the result of joining portions of two or more tables. A view appears to the user as a table and, under most circumstances, can be treated as such. Since views are the primary means by which a user retrieves data, views are also used to restrict data access.

Tables containing data collected to evaluate conditions at a mine were separated into views (one view per table) by mine. Tables containing data collected for other purposes were separated into views by the nonmining organization for whom the data were collected. These views represent portions of the tables. Views that are the result of joining tables were also created. Specifically, the historical data were separated into views by owner, where an owner may be a mine or a nonmining company.

The purpose for separating the data into tables and views in this manner is primarily to allow retrieval of data based on the sampling point name, even though two or more sampling points of the same type or of different types may have the same name. Considering that the data are separated into tables by sampling point type, and assuming that the following are true for each type of sampling point, the views do not contain data from two or more sampling points of the same name:

- The combination of the sampling point name and the owner name is unique

- The combination of the sampling point name and the name of the mine or non-mining organization for whom the data are collected is unique

Separating the data in this manner also eliminates the possibility of entering a null value in some columns of the tables. When possible, it is best to place the "not null" restriction on every attribute. This prevents data entry errors. Specifically, this prevents accidental entry of a null value when the value is actually known. If the data collected to evaluate conditions at a mine were combined with the other data, the not null restriction could not be placed on the column that stores the unique number of the mine for which the data were collected. In addition, if the data from all sampling point types were combined, the not null restriction could only be placed on the columns that apply to all types of sampling points.

An additional benefit to separating data in this manner is that smaller tables are created. Less time is needed to search for data in smaller tables. This method of separating data is also more user friendly because it simulates the manner in which users will tend to group and evaluate data. Users do not tend to evaluate data from different sampling point types in the same manner or at the same time.

The final benefit of separating the data in the described manner is related to the maximum value that can be represented by the hardware in computers with sixteen-bit registers, 32,767. If data from each sampling point were combined in a single set of tables, the system could only

assign a unique integer to 32,767 sampling points. Separating the data into tables by sampling point type allows the system to store data for 32,767 wells, 32,767 sediment ponds, etc.

ENTERING DATA

ORACLE provides three mechanisms for entering data into the data base: SQL, SQL*FORMS, and SQL*LOADER. SQL is the language upon which ORACLE is based. Commands such as INSERT are incorporated into the SQL language. SQL*FORMS is an ORACLE utility used to enter data interactively. SQL*LOADER is an ORACLE utility used to load data from ASCII, LOTUS, or DBASE files. SQL*FORMS and SQL*LOADER are used in our application.

SQL*FORMS is a powerful data entry tool for two reasons. Forms may be created on the screen that match actual forms from which the user enters data; and entry of data can trigger the execution of commands. For example, in the forms that were created for the WDEQ, entry of data from a new well triggers the system to determine the value of the last unique integer assigned to a well, add one to that value, assign the new value to the new well, and update the table that stores the value of last unique integer assigned to each entity. These commands are known as triggers. Triggers can be created for many purposes, including aiding the user in evaluating the quality of the data before the data are entered in the tables. WRI has developed a form for each table; however, we have only added a minimal number of triggers to each form. Our next step is to streamline the data entry process, mainly through the addition of more sophisticated triggers.

SQL*LOADER is similar to a conventional job-control programming language in that a control file is created to direct computer operation (in this case, how to load the data). Code can be added to the control file to perform such tasks as assigning a unique number to each new entity or screening data that do not meet specific requirements. Prior to the onset of this project, the WDEQ loaded much of their data into a nonrelational commercial data base known as REFLEX. WRI is in the process of transferring this data to ASCII files and loading the data into the ORACLE data base using SQL*LOADER. In addition, WRI is developing the formats in which the mining companies will be requested to submit their data. SQL*LOADER will be used to load data that are submitted on tape in these formats. If there are errors in our data model, it is anticipated that the majority will be identified during the loading process.

RETRIEVING DATA

ORACLE provides three tools for retrieving data: SQL, SQL*FORMS, and SQL*REPORTWRITER. As mentioned earlier, SQL is the language upon which ORACLE is based. Like SQL*FORMS, SQL*REPORTWRITER is an ORACLE utility.

SQL can be used to create quick reports. These reports do not have titles, etc. It is suggested that users retrieve data using SQL unless a

formal report format is required. ORACLE offers the option to store the retrieved data and the commands used to retrieve the data in ASCII files. In addition, SQL commands may be imbedded in programs written in other languages provided the user owns the ORACLE precompiler for that language.

The data base can be queried within SQL*FORMS. However, it is suggested that other mechanisms be used to create reports because the forms do not transfer accurately to some printers.

SQL*REPORTWRITER is used to create formal reports complete with titles, footnotes, etc. It may be easier to add text with a word processor, rather than using SQL*REPORTWRITER.

In the future, WRI will compile and store the commands needed to create reports that are commonly used by the WDEQ. Command sets will also be compiled to create the input files for computer programs that help the WDEQ to evaluate the quality of their data and characterize conditions at a mine.

ROLE OF THE DATA BASE ADMINISTRATOR

By creating views of the tables, WRI has created a mechanism for protecting the data. However, most of the responsibility for data protection will lie with WDEQ's data base administrator. The administrator will assign table and view access privileges, backup the data base, and audit access to the system.

The OSM/WDEQ data management system will be executed on personal computers. An additional responsibility of the data base administrator will be to ensure that the same version of the data management system is loaded on each computer.

TESTING AND STREAMLINING THE DATA MANAGEMENT SYSTEM

Testing the system to determine if it meets with the primary objective of the project is a continuous process. Each step in developing the data management system leads to the testing and streamlining of previous step results. In the near future, WRI will use a public domain computer program developed at the University of Wyoming to determine if the data base tables are in normalized form and if functional dependencies are maintained. That is, we are making sure that the user can examine all relationships with our model that are of interest to the user, and that our model includes as few tables as possible.

We will also be evaluating the effects of clustering versus indexing. The purpose of clustering is to reduce the time it takes to complete a query, and reduce the amount of space required to store the tables. Clustering is accomplished by storing tables together and eliminating redundant data.

INSTRUCTING THE USER

WRI is creating a user's manual and a course to instruct the WDEQ and others on the use of the system. The manual is in the development stages. We will begin development of the classnotes in the near future. The course will include an introduction to ORACLE.

FURTHER WORK

Depending on time and funding, WRI will expand the data base to include overburden and vegetation data. We will also enhance the system by making it menu driven.

Upon completion of the data management system, the system will be offered to coal mining regulatory agencies in other states through OSM's technical information processing system (TIPS) program. In addition, the data management system will be loaded into the Wyoming Water Research Center's Water Resource Data System (WRDS), located on the University of Wyoming's VAX mainframe computer.

Finally, it should be noted that the OSM/WDEQ data management system can be adapted to store and evaluate data from any site at which hydrologic data are collected. In the near future, WRI hopes to adapt the system to contain data collected from sites in addition to surface coal mining operations.

REFERENCES

Relational Systems Corporation. 1985. Relational Data Base Design. Extended Relational Analysis Workshop V5.1. Relational Systems Corporation, Birmingham, MI.

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